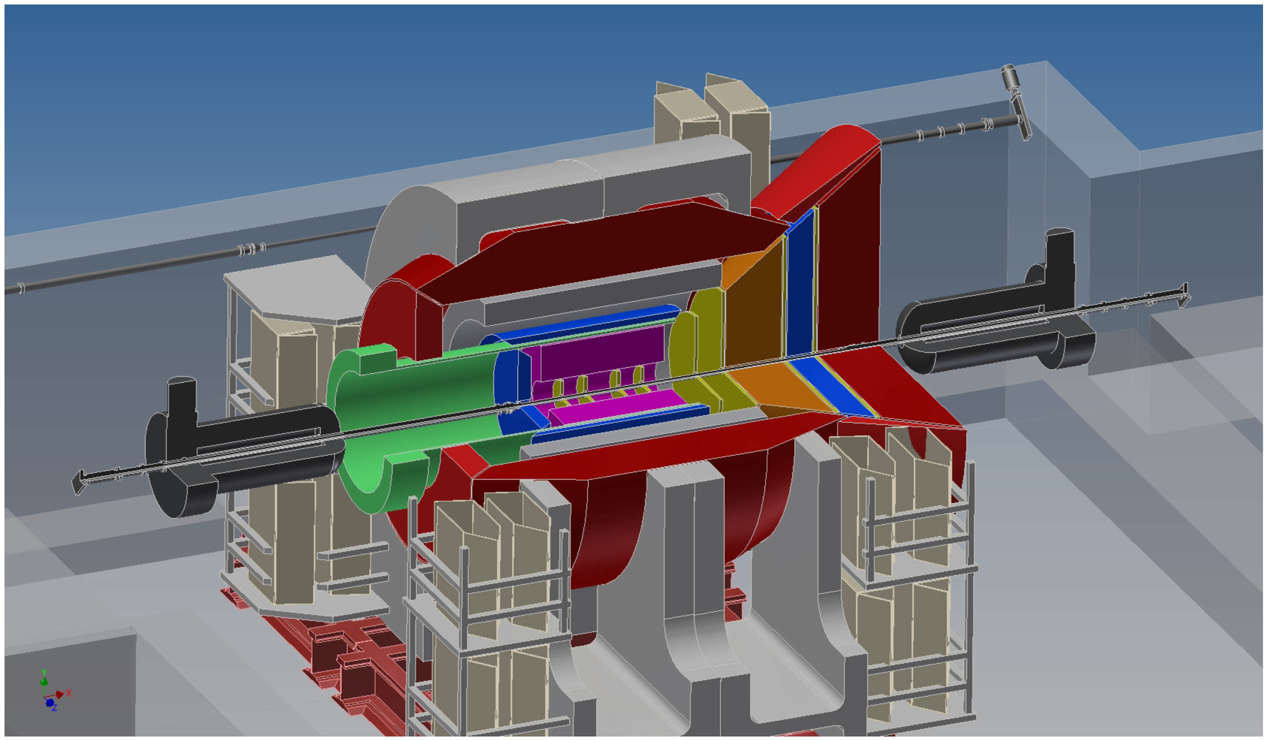


A.Bazilevsky

For PHENIX Collaboration

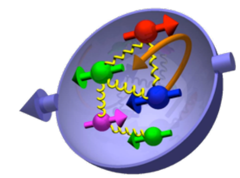
Outline

- EIC Physics
- Detector Concept
- Detector Performance
- Physics Capabilities

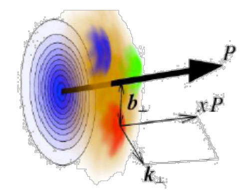
EIC Physics

Well developed and summarized in:
INT EIC report: arXiv:1108.1713
EIC White Paper: arXiv:1212.1701

Distribution of quarks and gluons and their spins in space and momentum inside the nucleon

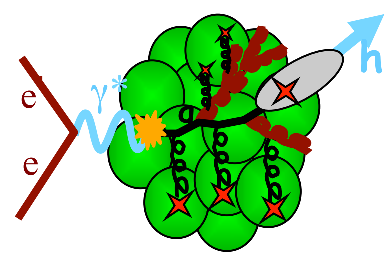


- Nucleon helicity structure
- Parton transverse motion in the nucleon
- Spatial distribution of partons and parton orbital angular momentum



QCD in nuclei

- Nuclear modification of parton distributions
- Gluon saturation
- Propagation/Hadronization in nuclear matter

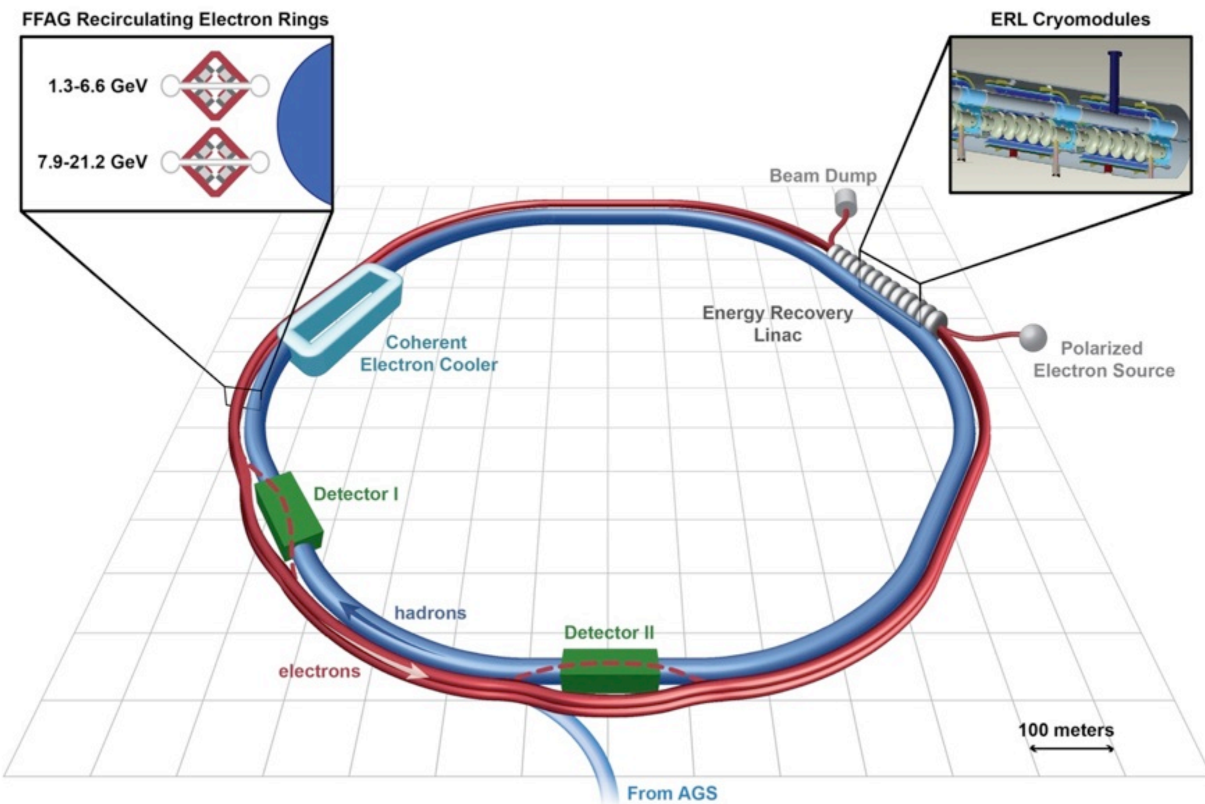


~~Weak interactions & beyond standard model~~

- Require highest energy and lum. -> not for stage-1

eRHIC

ep/eA



In current design:

Energy:

Electron: 6.6–21.2 GeV
Proton: 25–250 GeV
Ions: 10–100 GeV
$\sqrt{s}$: up to 145 GeV

Polarization:

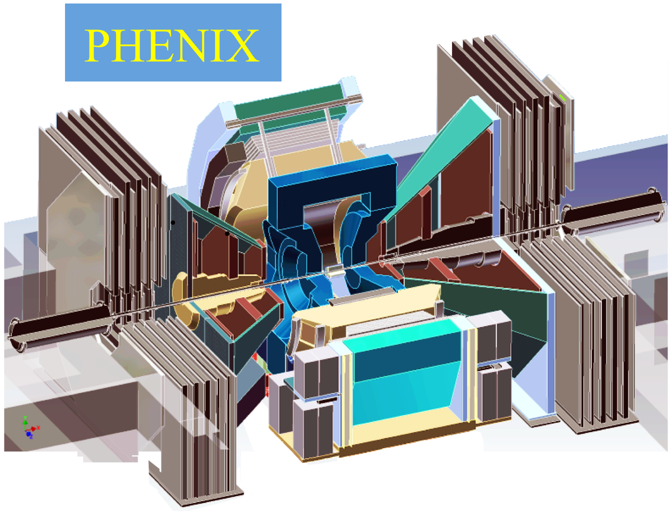
Electrons: 80%
Protons and He3: 70%

Luminocity:

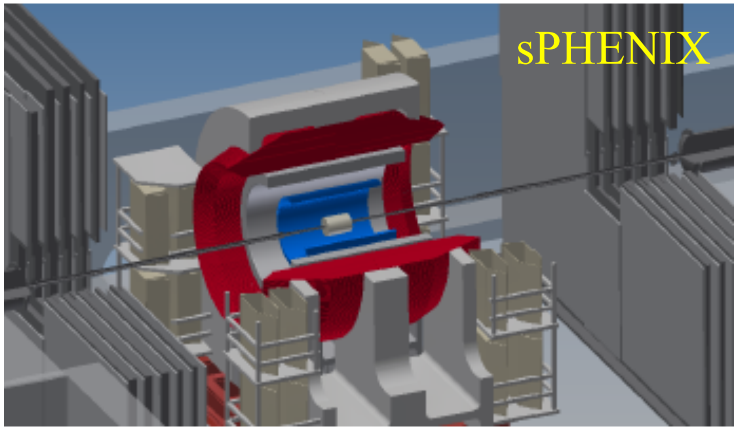
$>10^{33}$ cm^{-2} s^{-1}

… Still evolving

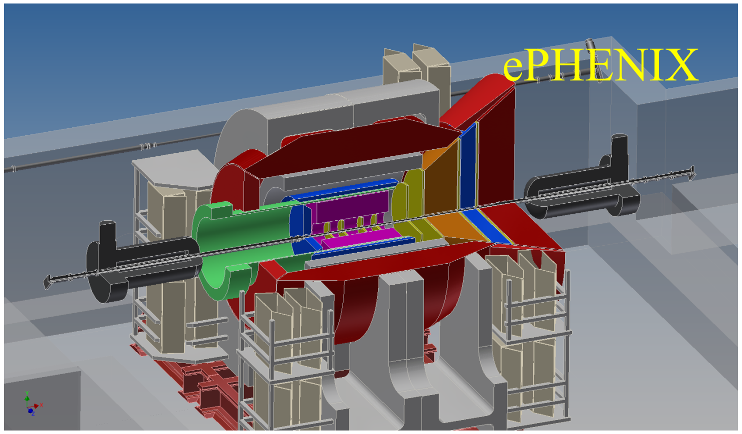
PHENIX -> ePHENIX Path



By ~2020



By ~2025



Evolve sPHENIX (pp and HI detector) to ePHENIX (DIS detector)

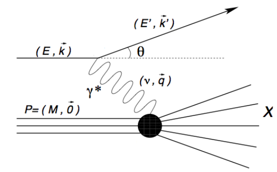
- To utilize e and p (A) beams at eRHIC with *e*-energy up to 15 GeV and *p*(*A*)-energy up to 250 GeV (100 GeV/n)
- *e*, *p*, *He*3 polarized
- Stage-1 luminosity ~10^{33} cm^{-2} s^{-1} (~$1fb^{-1}$ /month)

General Detector Concept

Inclusive DIS and scattered electron measurements

With focus in e-going direction and barrel

High resolution EMCal and tracking; minimal material budget

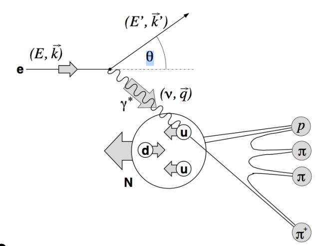


Semi-inclusive DIS and hadron ID

With focus in h-going direction and barrel

Barrel: DIRC for p_h<4 GeV/c

h-going direction: aerogel for lower p_h and gas RICH for higher p_h

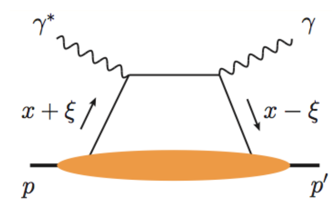


Exclusive DIS (DVCS etc.)

EMCal and tracking coverage in -4<η<4

High granularity EMCal in e-going direction

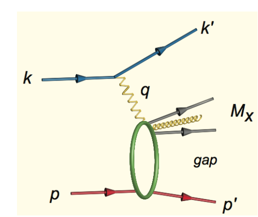
Roman Pots in h-going direction



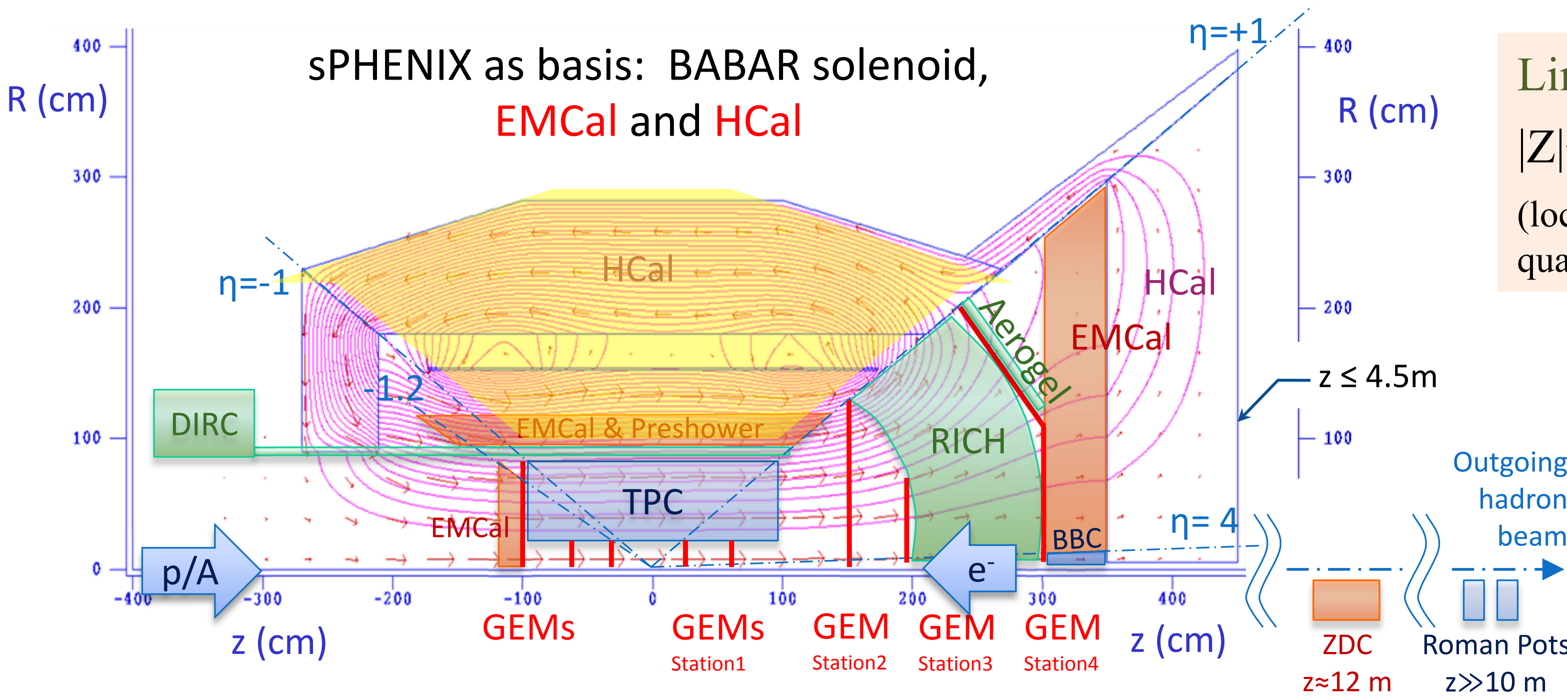
Diffractive

Rapidity gap measurements: HCal in -1<η<5; EMCal in -4<η<4

ZDC in h-going direction



ePHENIX Detector Concept



Limitation:

|Z|<4.5m

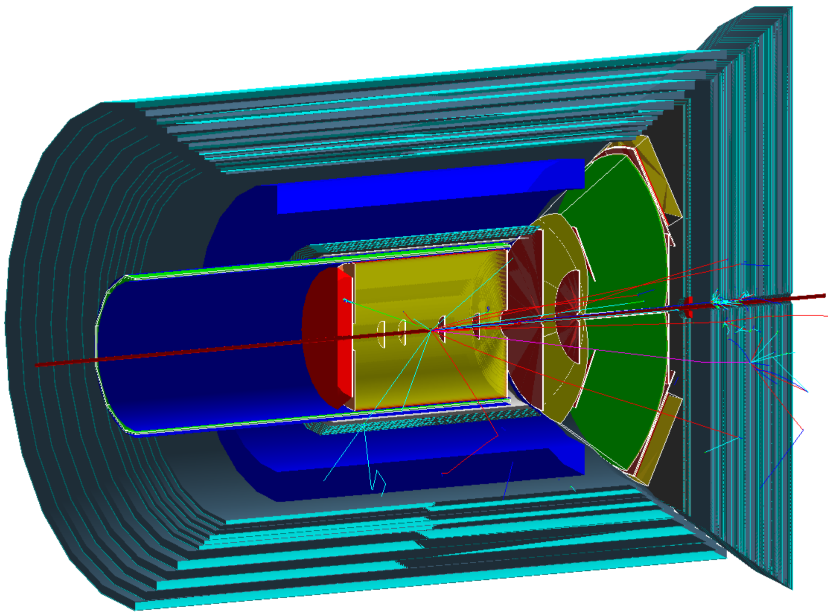
(location of focusing quadrupoles)

- -4<η<-1 (e-going):
  - Crystal calorimeter with high energy and position resolution
  - GEM Trackers
- -1<η<1 (barrel):
  - Add Compact-TPC and DIRC
- 1<η<4 (h-going):
  - HCal & EMCal (1<η<5)
  - GEM Trackers
  - Aerogel RICH (1<η<2)
  - Gas RICH
- Far Forward (h-going)
  - ZDC and Roman Pots

ePHENIX performance evaluation

Generators:

PYTHIA, MILOU (for DVCS), RAPGAP (diffractive), RADGEN (rad. effects)
Thanks to BNL EIC group for maintaining them at racf



GEANT4 description of ePHENIX

Simulation and analysis software common with sPHENIX and PHENIX

Experience from previous DIS experiments:

SLAC, CERN, DESY, Jlab
Also studies and developments from BNL EIC group

BaBar Magnet

BaBar solenoid in its transfer frame, May 17 2013

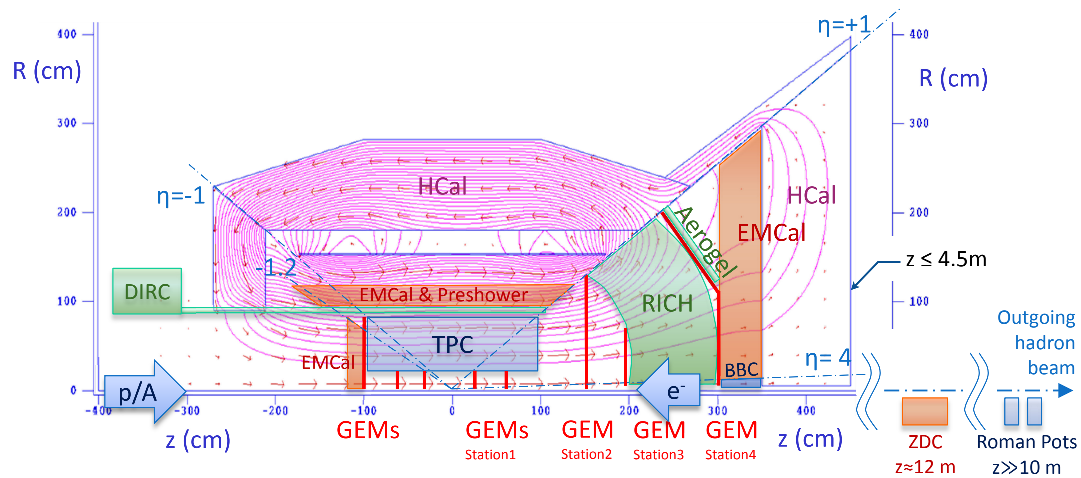
Major Parameters:

- ✓ Superconducting Solenoid
- ✓ Field: 1.5T
- ✓ Inner radius: 140 cm
- ✓ Outer radius: 173 cm
- ✓ Length: 385 cm

Higher current density at magnet ends and field shaping in forward angles provide high analyzing power for momentum determination in e-going and h-going directions

Flux return and field shaping:

Forward HCal
Steel lapmshade
Barrel HCal
Steel endcup



Main space limitation observed: |z|<4.5m
(due to focusing magnet location)

Tracking Detectors

- Central tracker:
  - TPC similar to LEGS TPC
  - 15<r<80 cm, |z|<95 cm
  - Low mass
  - Read out on both ends
  - 40 readout raws
  - Pos. Res. of 300 μm
- Forward/Backward tracker:
  - Multiple GEM stations
  - 50-100 μm resolution in $r\Delta\phi$
  - e-going tracker used for improved EID

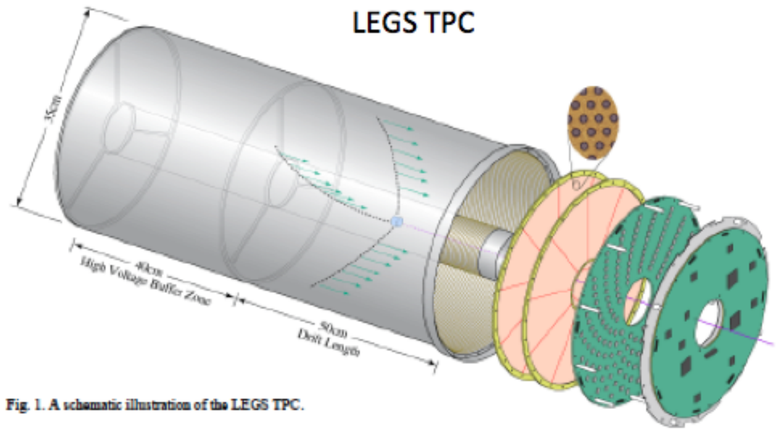
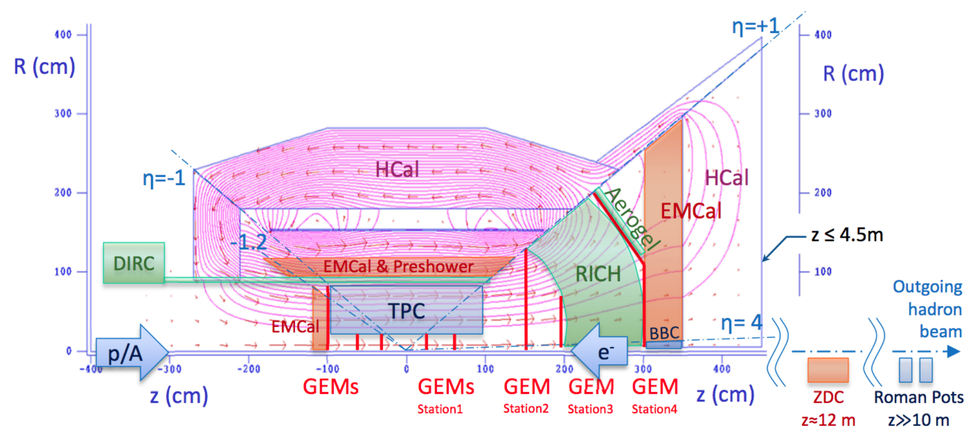
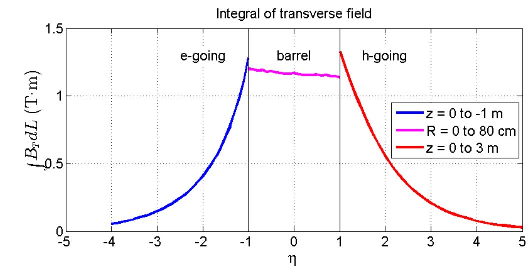


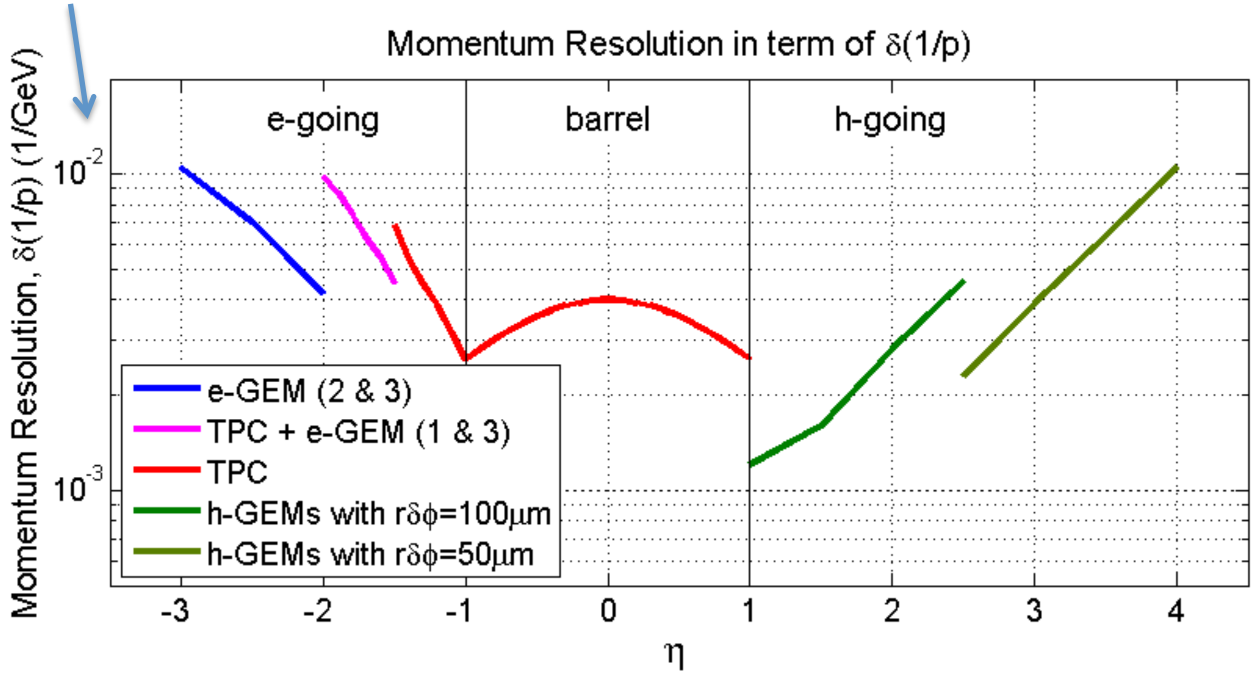
Fig. 1. A schematic illustration of the LEGS TPC.



Momentum Resolution



$\delta p/p \sim a \times p$

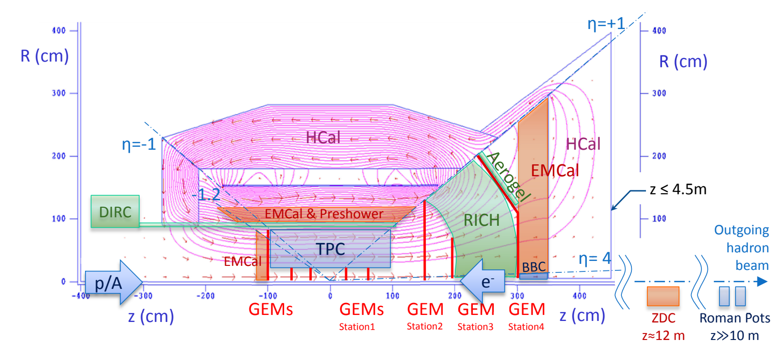


Good resolution over full tracking acceptance (-3<η<4):

e-going, $\sigma_p/p \sim (0.4\text{-}1.0\%)\times p$: primarily needed for electron ID (E/p)

barrel, $\sigma_p/p < 0.4\%\times p$: hadron momentum, electron momentum at p<10 GeV/c

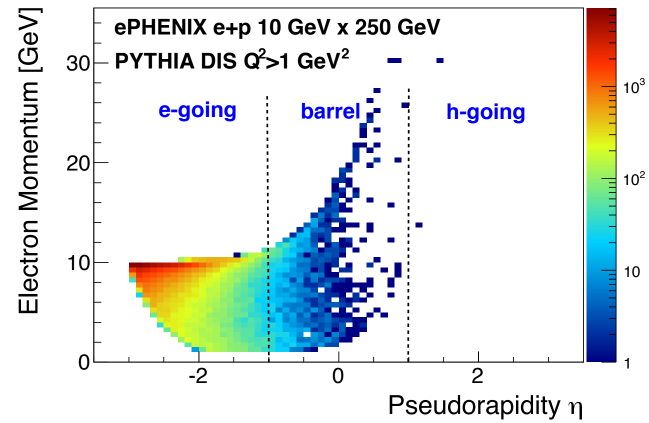
h-going, $\sigma_p/p \sim (0.1\text{-}1.0\%)\times p$: crucial for PID

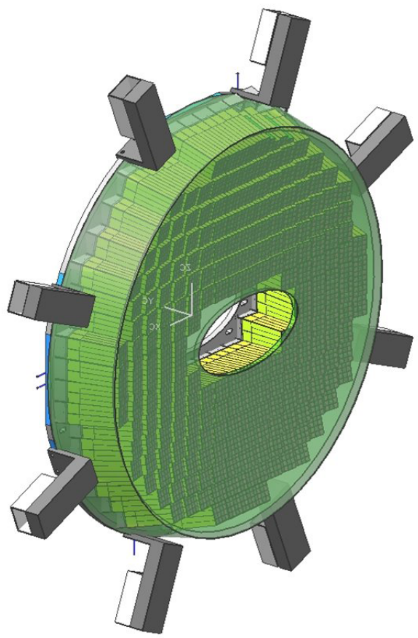


EM Calorimetry and DIS kinematics

Measure scattered electron energy and angle:

$$Q^2 = 4EE'\sin^2\left(\frac{\theta}{2}\right) \qquad y = 1 - \frac{E'}{E}\cos^2\left(\frac{\theta}{2}\right) \qquad x = \frac{Q^2}{sy}$$

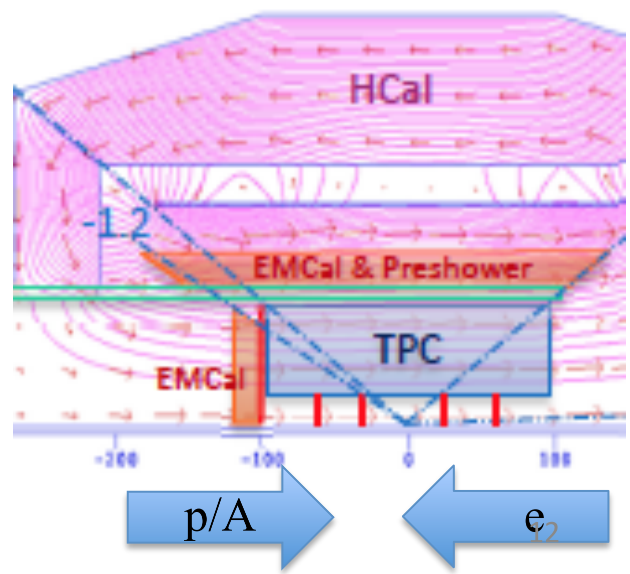




TDR for PANDA
arXiv:0810.1216

- Endcap Calorimeter:
  - $PbWO_4$ crystal
  - Similar to PANDA endcap design
  - $\sigma_E/E \sim 1.5\%/\sqrt{E}$
  - $\sigma_X < 3mm/\sqrt{E}$
- Barrel Calorimeter:
  - sPHENIX EMCal
  - Tungsten based
  - $\sigma_E/E \sim 12\%/\sqrt{E}$

Scattering mainly in e-going direction and barrel



Inclusive DIS and Kinematics

eID and background rejection

Hadron rejection:

EMCal energy response and E/p

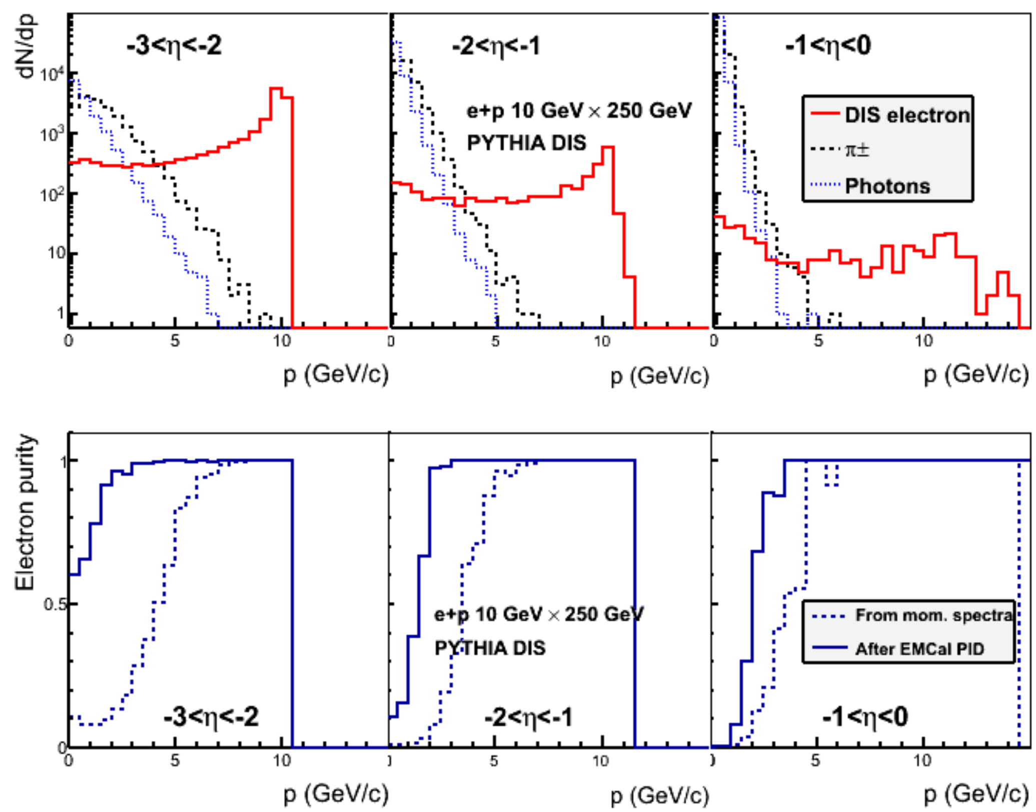
- ×20-30 at 1 GeV/c
- ×100 at 3 GeV/c

EMCal shower profile

- Expect ×3-10
- Not yet included in plots

EMCal long. segmentation and/or preshower

- For future considerations



Photon rejection ($\gamma \rightarrow e^+e^-$)

Minimal material

GEANT studies:

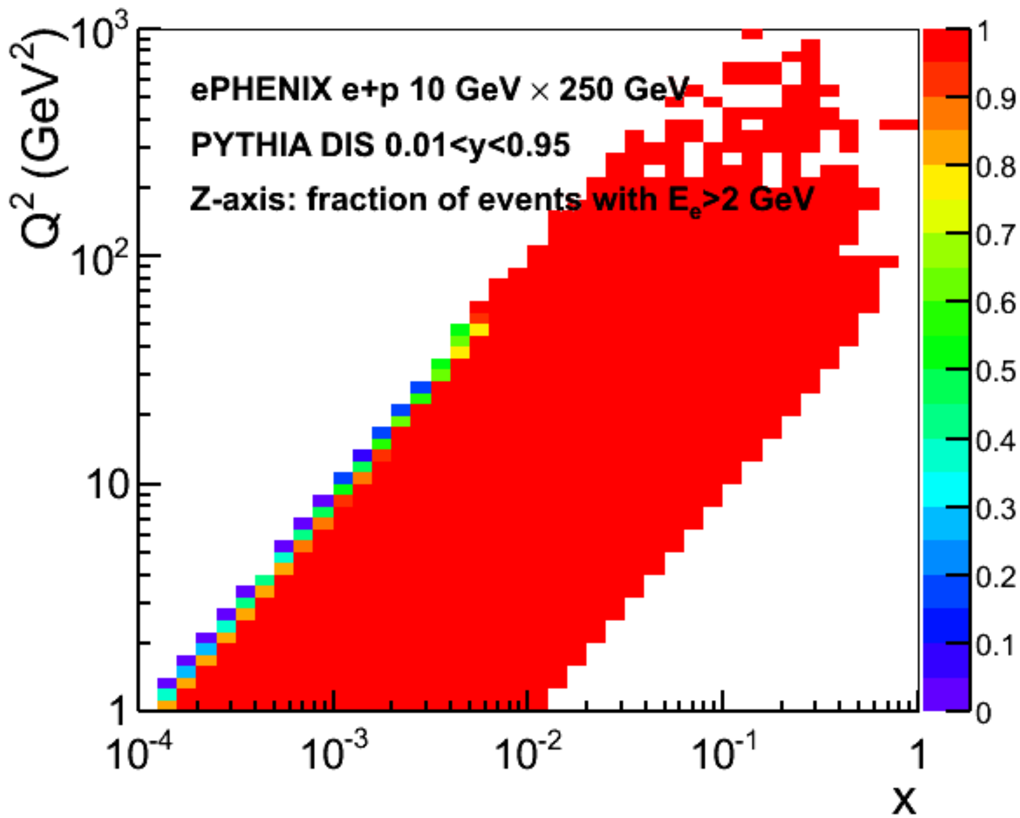
- >3 GeV/c: background negligible
- <3 GeV/c: rejected with tracking+EMCal

Reliable eID down to
- p=2 GeV/c for 10 GeV e-beam
- p=1 GeV/c for 5 GeV e-beam

Inclusive DIS and Kinematics

What if poor eID at <2 GeV/c

Don't lose much of the (x,Q^2) space



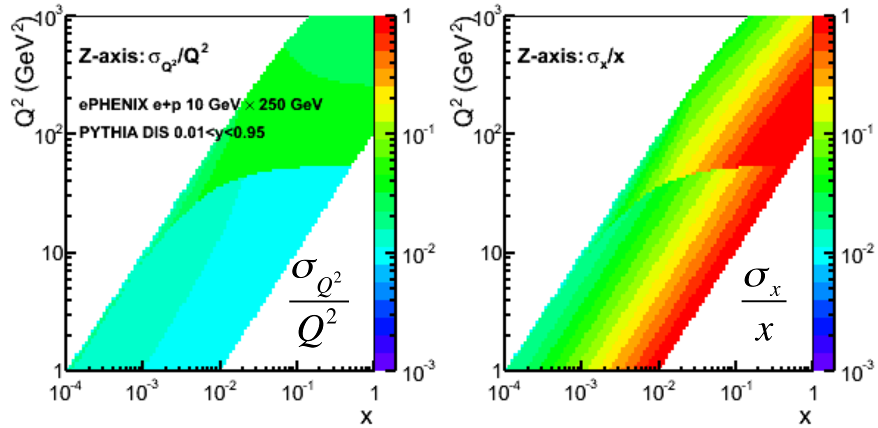
Inclusive DIS and Kinematics

Resolutions for (x,Q^2)

For perfect angle measurements:

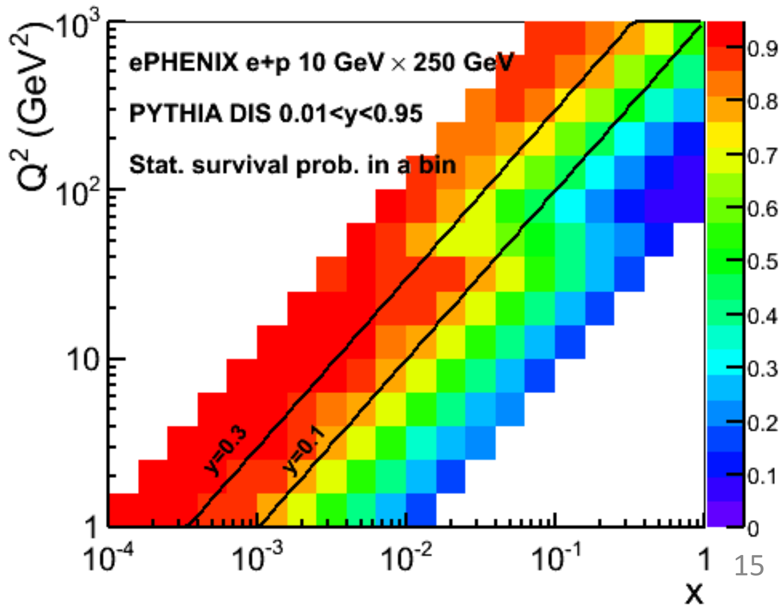
$$\frac{\sigma_{Q^2}}{Q^2} = \frac{\sigma_{E'}}{E'} \qquad \frac{\sigma_x}{x} = \frac{1}{y}\frac{\sigma_{E'}}{E'}$$

Defines the precision of unfolding technique to correct for smearing due to detector effects



Results in statistics migration from bin to bin –> bin survival probability

From HERMES experience: ~80% needed



Enough precision for scattered angle from EMCal position resolution –> no effect on bin survivability

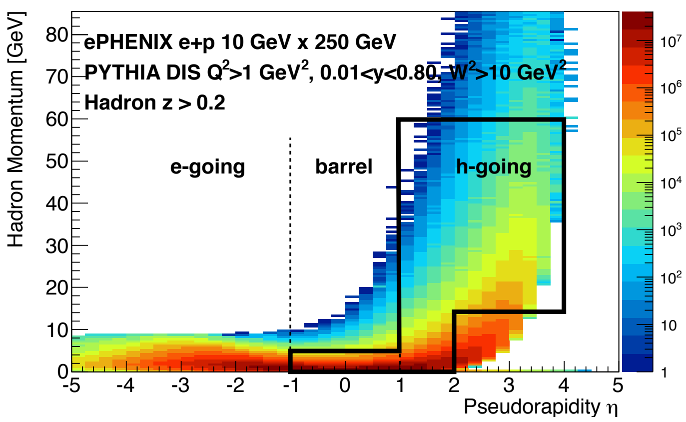
Jacqet-Blondel method (with hadronic final state) will help at lower y and higher Q^2

Bremsstrahlung radiation: no sizable effect

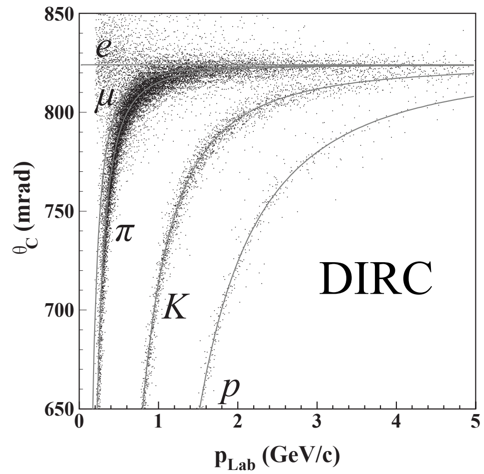
Minimal material

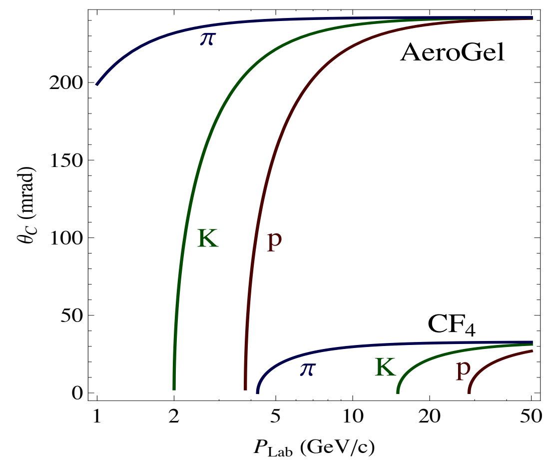
GEANT: 3-7% impurity for y=0.5-0.95

Semi-inclusive DIS and hadron ID



Focus on h-going direction and barrel





DIRC:

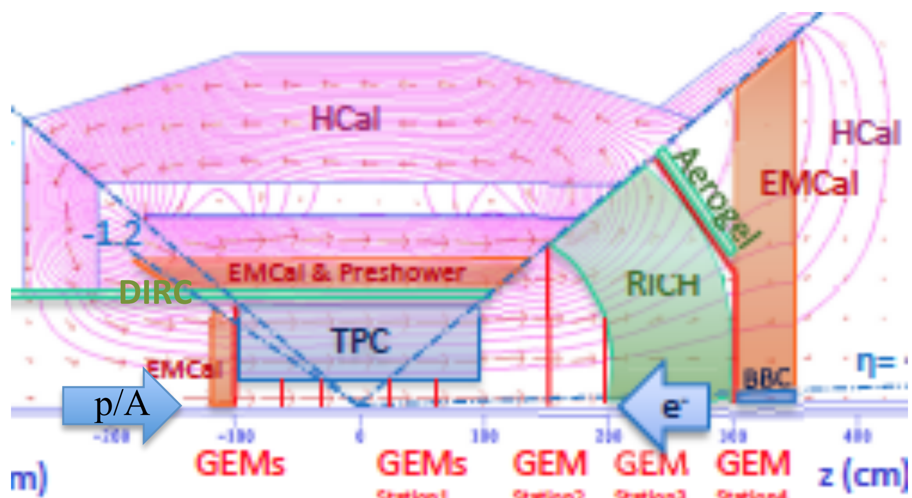
- $-1<\eta<1$
- PID at <4 GeV/c

Aerogel:

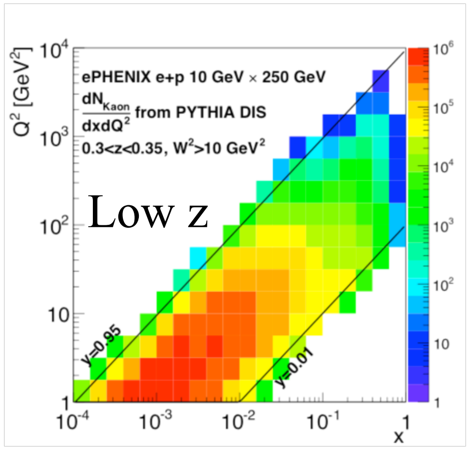
- $1<\eta<2$
- PID at <15 GeV/c

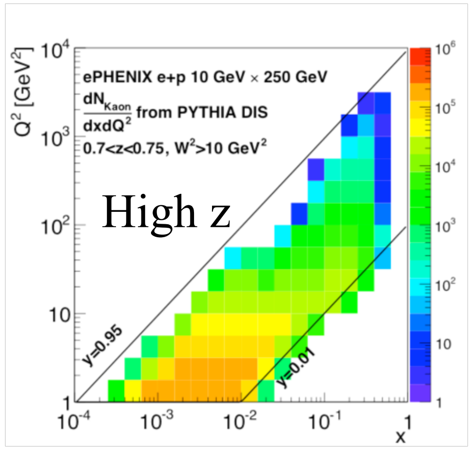
Gas RICH (CF4):

- $1<\eta<4$
- PID at <60 GeV/c



Semi-inclusive DIS and hadron ID



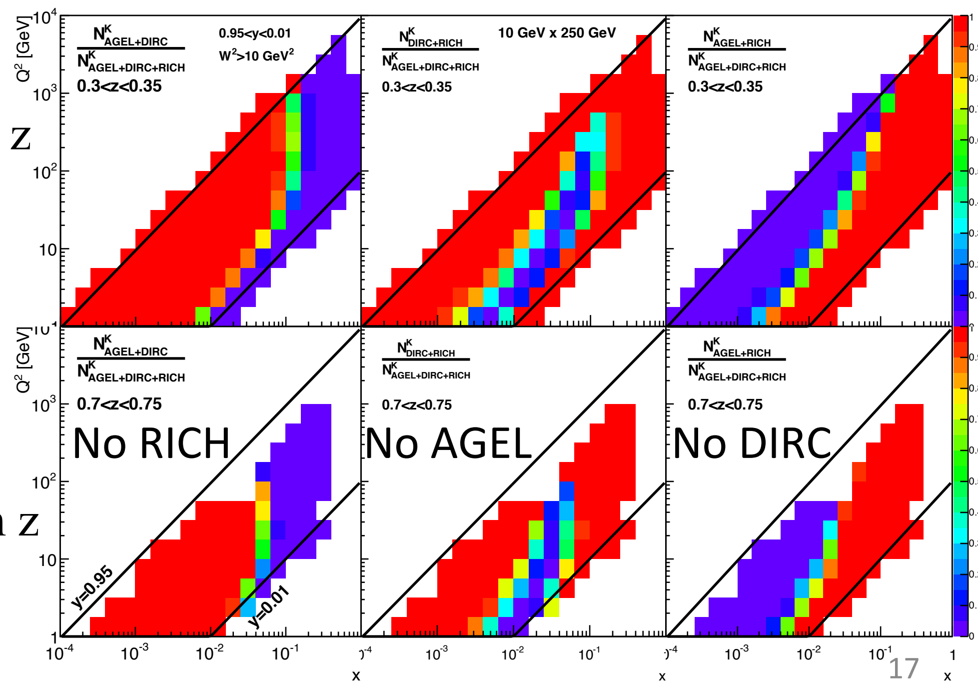


(x,Q^2) coverage with K

(x,Q^2) loss if not have given detector

Low z

High z



All three detectors are important

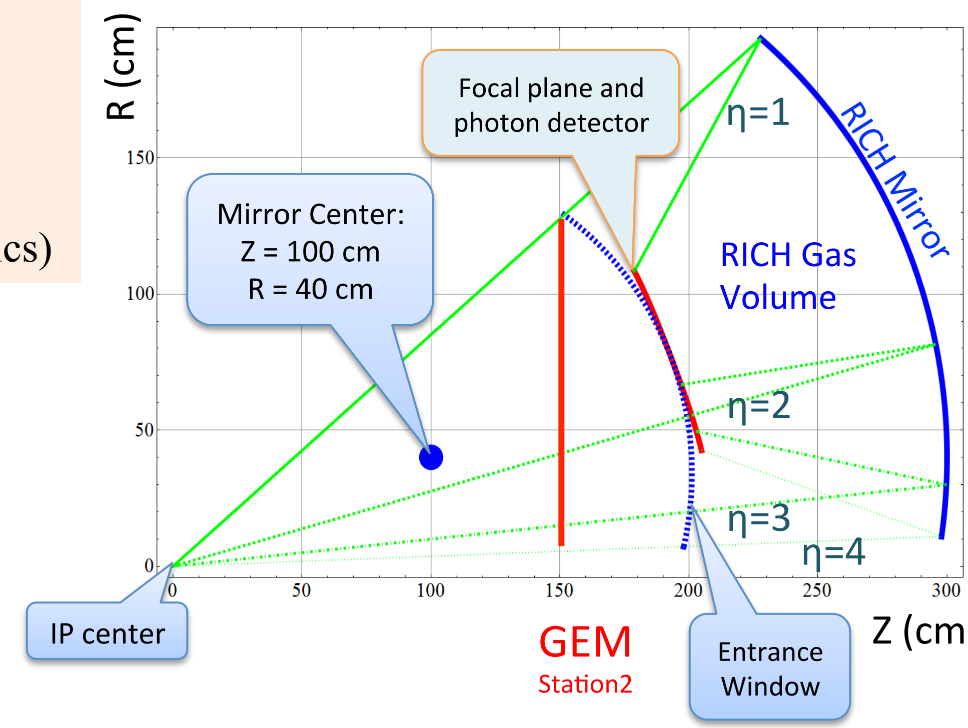
Gas RICH

CF4 (n=1.00062)

Based on current EIC R&D project

Focusing plane in acceptance

Use GEM as thin (and flat in proposed optics)



Ring resolution:

Ring radius resolution: $2.5\%/\sqrt{N_\gamma}$

From current EIC R&D studies

LHCb and COMPASS claimed 1% per photon

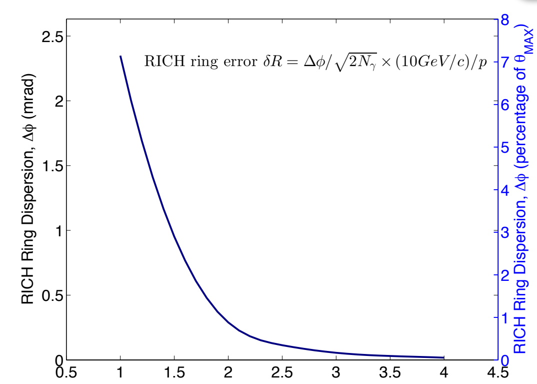
Residual magnetic field (~0.5 T) bends tracks radiating photons => ring smearing

Since field is near parallel to tracks the effect is minimal

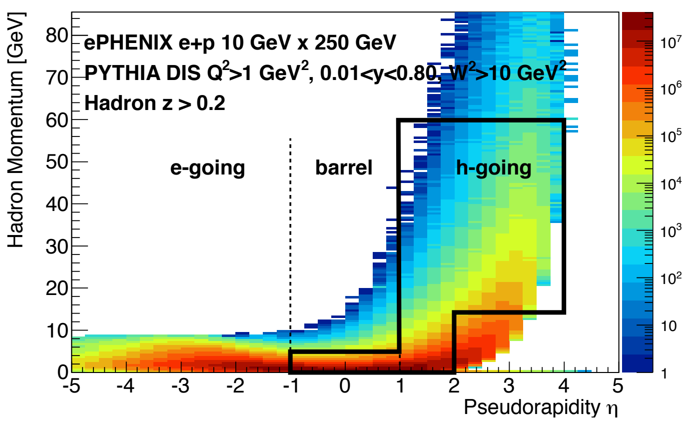
Off-center vertex tracks have shifted focal plane => ring smearing

For η=1 and z=40cm => ring dispersion $5\%/\sqrt{N_\gamma}$

For larger η effect is smaller



Hadron ID with gas RICH

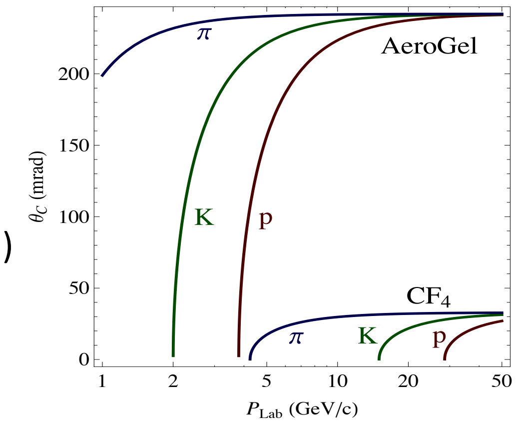


Gas RICH (CF4): 1<η<4

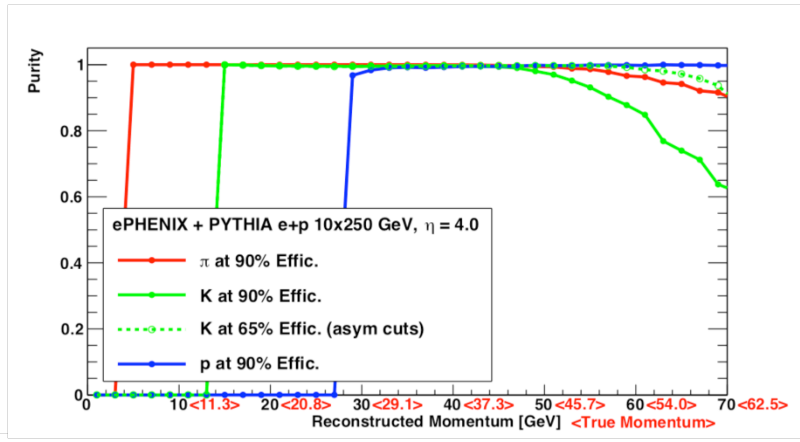
Highest momentum measurements require:

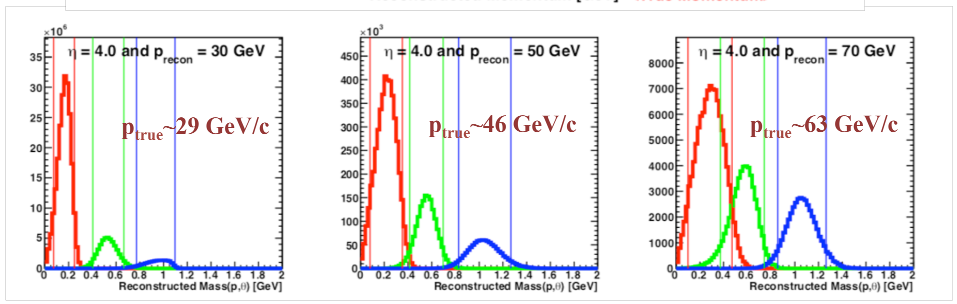
- Good momentum resolution (combination of tracking and HCal)
- Good ring resolution

Need to balance efficiency and purity to get best measurement



- PID up to ~60 GeV/c
- Currently limited by ring resolution (2.5% per photon - the current feedback from EIC R&D)
- Much smaller smearing due to magnetic field and off-center-vertex tracks





Hadron measurements with HCal and Tracking

At very forward rapidity (η~4) HCal energy resolution for single tracks may considerably exceed tracking momentum resolution

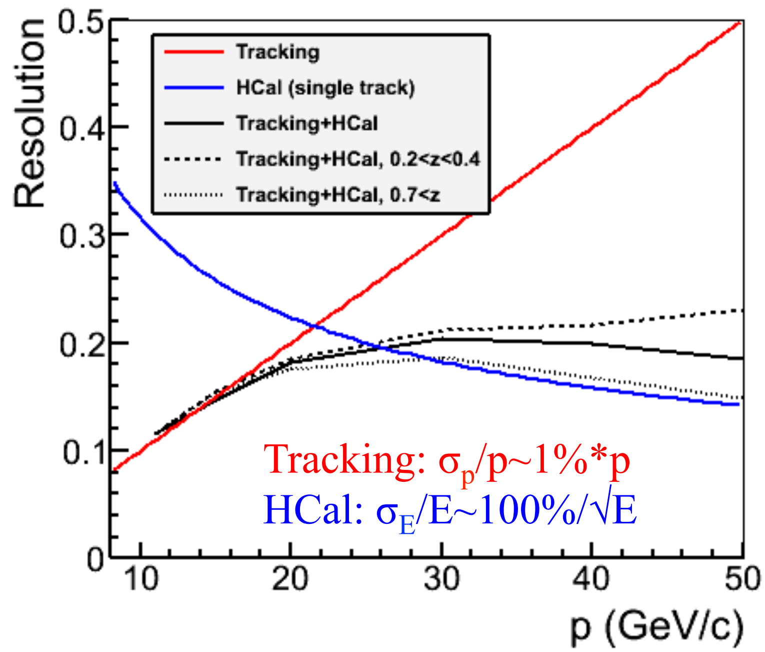
Can HCal be used to measure energy (momentum) of high momentum tracks ?

The main concern is that the energy depositions of tracks in vicinity of a given track are merged in a single cluster in HCal (non-separable in HCal)

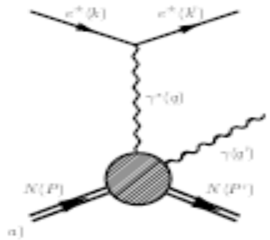
The idea:

- Usual event structure is that there is one high momentum leading particle with a few lower momentum particles;
- Low momentum particles are supposed to be well reconstructed with tracking, so their contribution in HCal can be evaluated and subtracted to calculate the energy deposition of the leading high momentum particle.

PYTHIA simulation



Full GEANT4 simulation is ongoing
The main impact is expected from tracking eff. and ghost (high momentum) tracks



Exclusive Measurements

DVCS:

Wide coverage for photon measurements

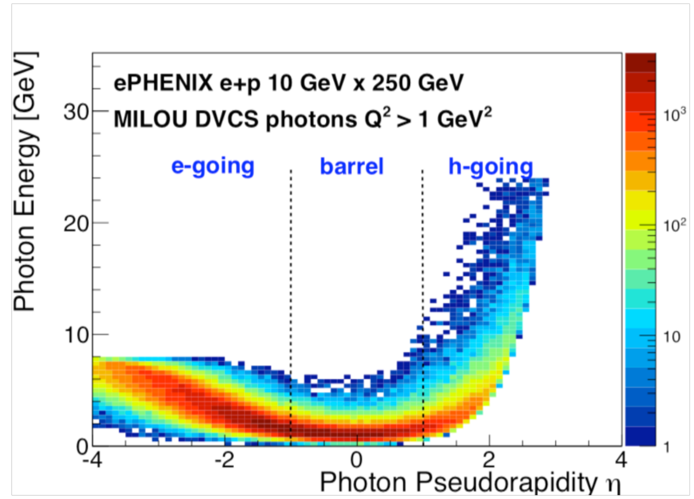
- EMCal and tracking in |η|<4

Separation of e-γ in EMCal

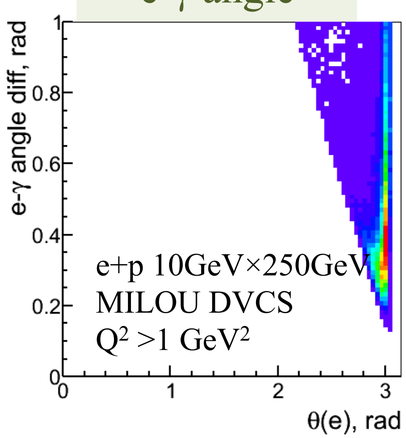
- 0.02×0.02 EMCal granularity is sufficient

Intact proton detection is highly desirable

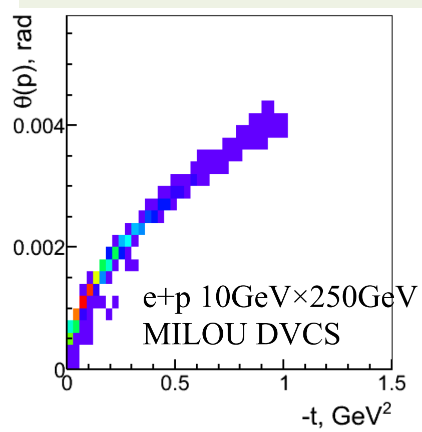
- Roman Pots



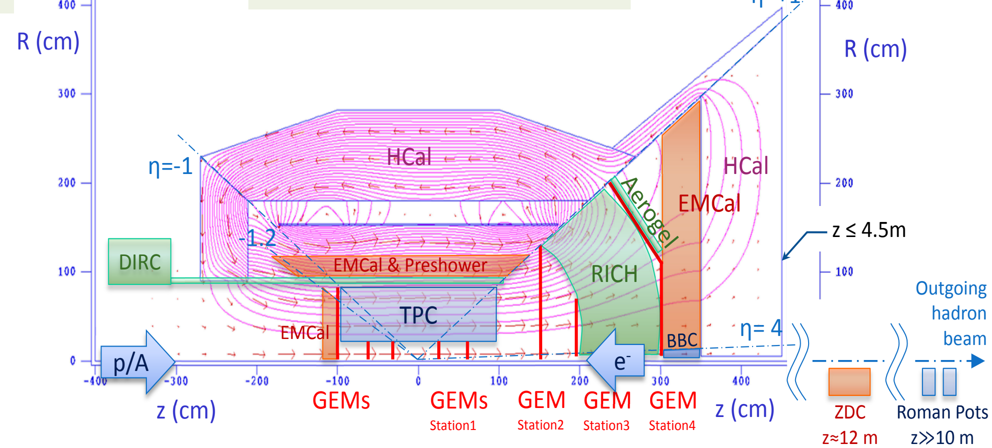
e-γ angle



Proton scattering angle



ePHENIX coverage

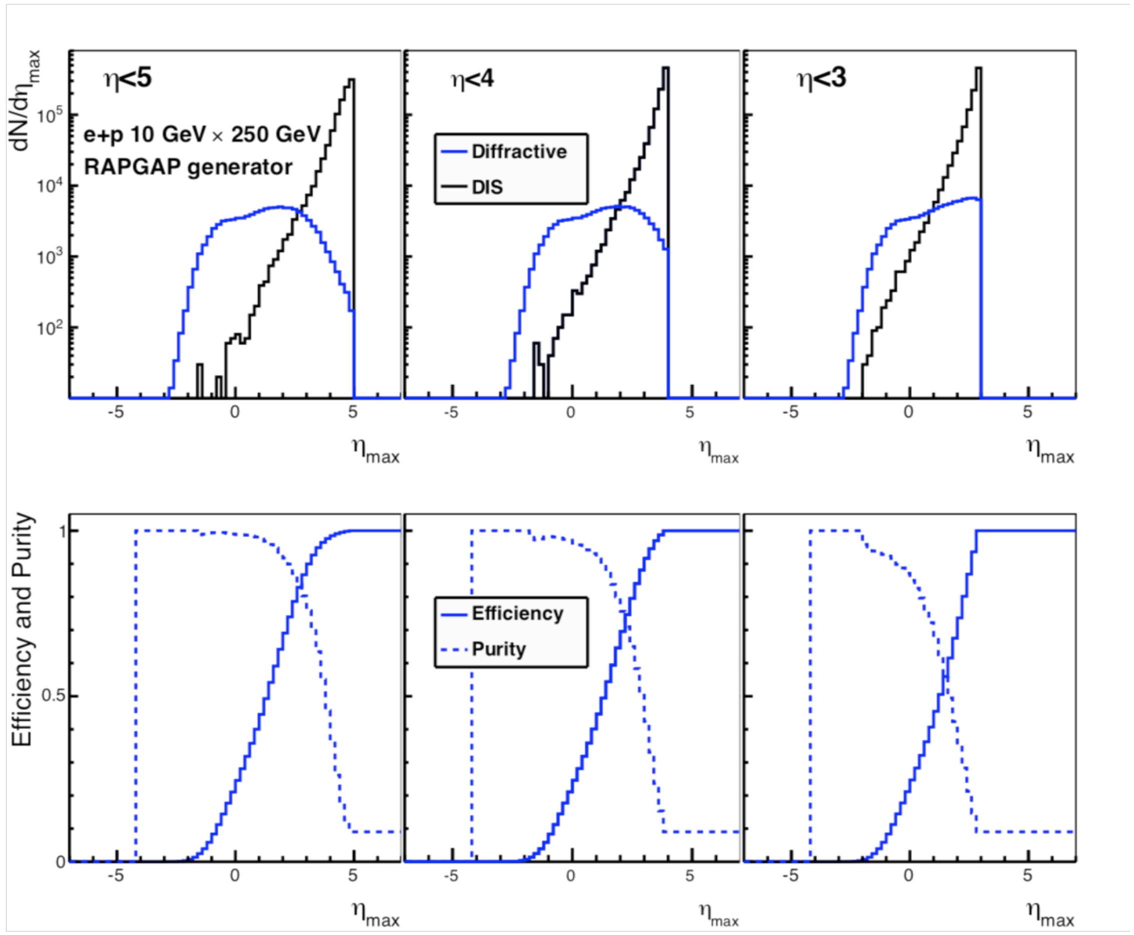


Diffractive Measurements

- Measure most forward going particle, to determine rapidity gap

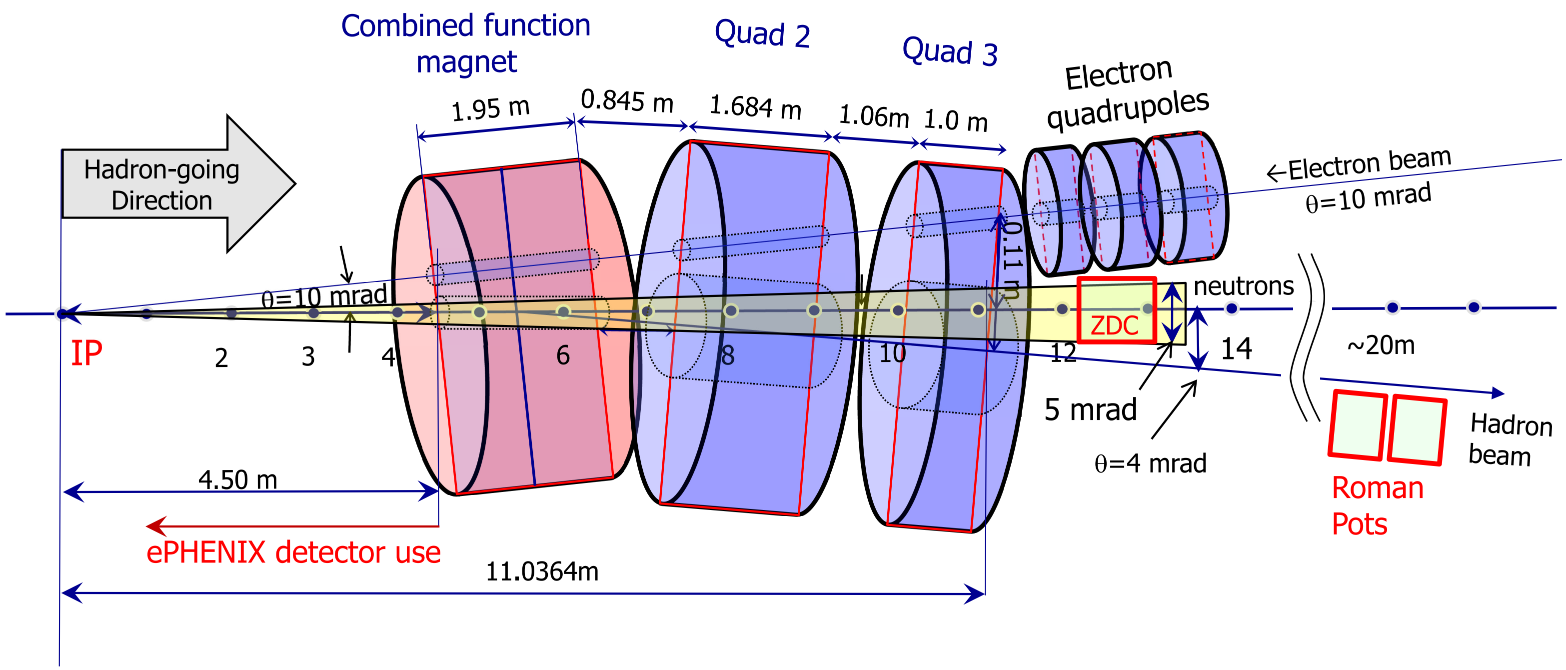
  HCal with -1<η<5 and EMCal with -4<η<4 are excellent in separation of DIS and diffractive

- ZDC to measure nucleus breakup



Beamline Detectors

Similar to all eRHIC detectors, being designed in parallel with IR design



ZDC

12 m downstream

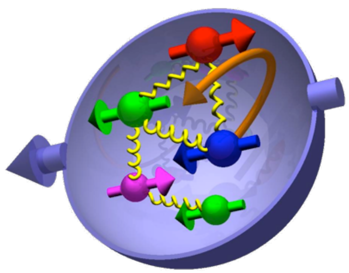
5 mrad cone opening of the IP is available from ePHENIX and IP design

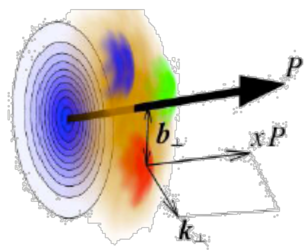
Roman Pots

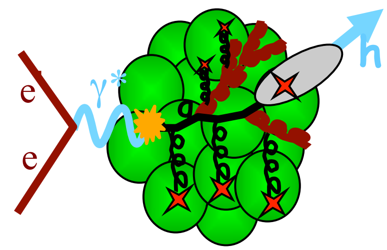
>20 m downstream

Similar to STAR design

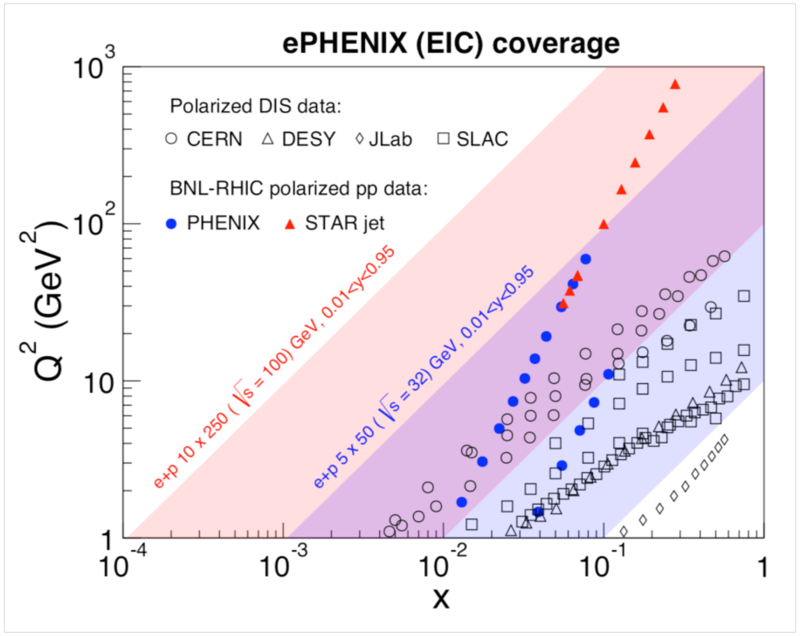
Physics Expectations







Proton structure: long. spin



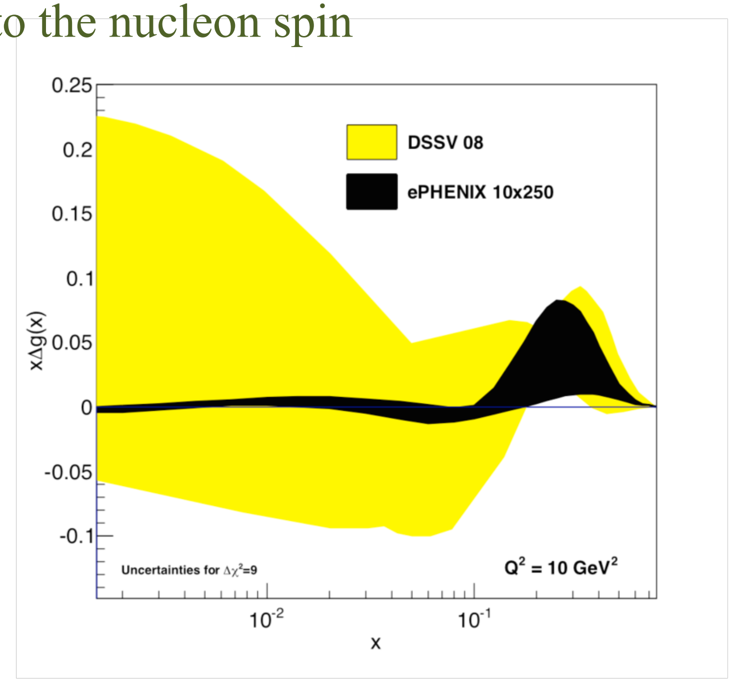
Inclusive and semi-inclusive DIS

Unique capability to reach much lower x and span a wider range in Q^2 (particularly important for gluon distributions)

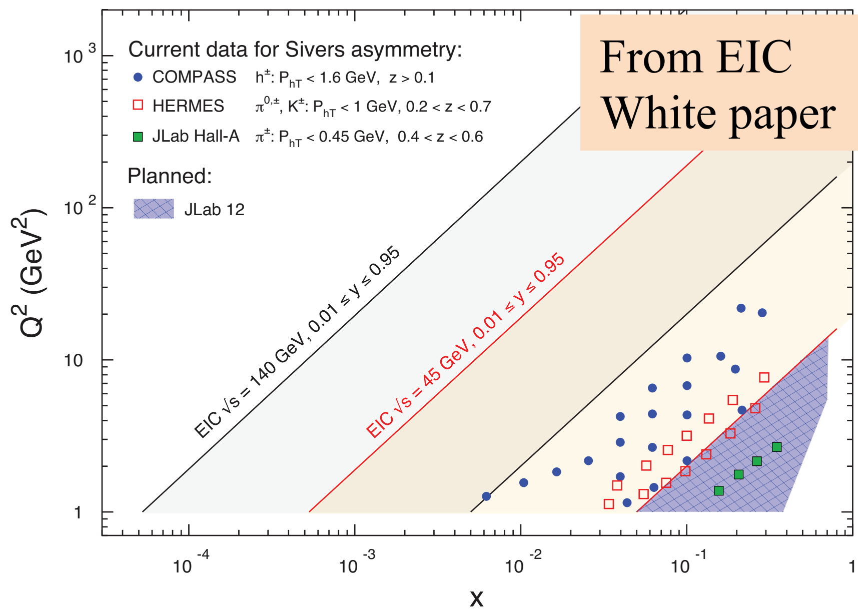
=> Precise evaluation of the long. spin component of the gluons and flavor separated (sea)quarks to the nucleon spin

PHYTHIA generator and ePHENIX acceptance/efficiencies

10 fb^{-1} at 10GeV×250GeV



Motion of confined gluons and quarks



From EIC White paper

Semi-inclusive DIS

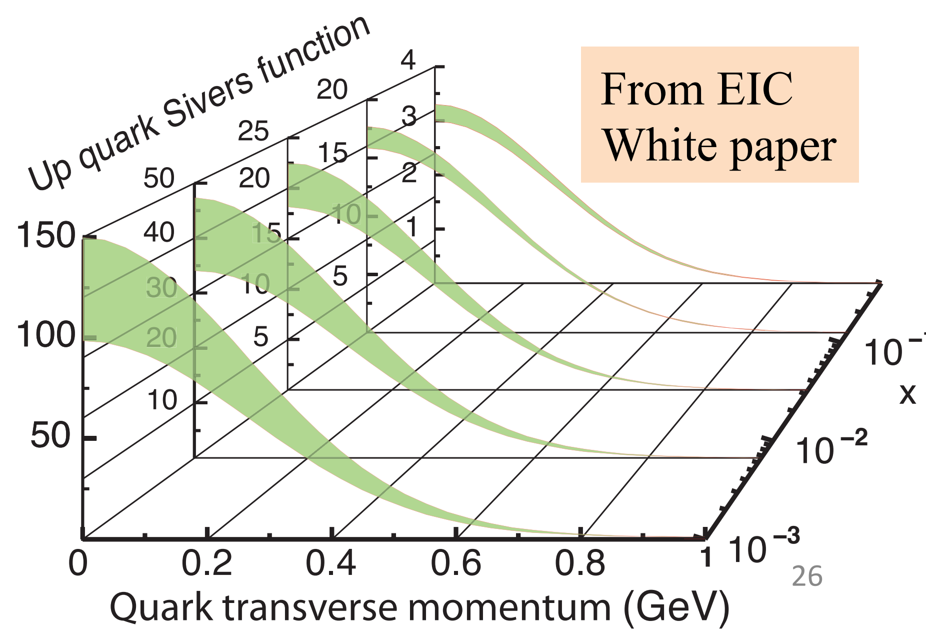
Transverse Momentum Distributions (Sivers)

Greatly expand x&Q^2 coverage

High luminosity => fully differential analysis over x, Q^2, z and P_{hT}

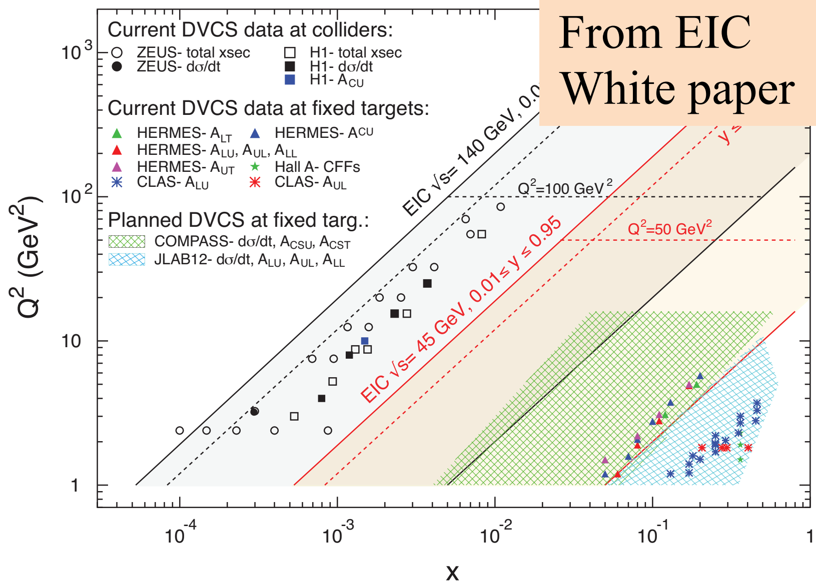
For the first time, determination of Sivers distributions over wide range in x will be possible

We're working on evaluation of expected Sivers constraint with ePHENIX data



From EIC White paper

Proton Tomography



From EIC White paper

Exclusive DIS

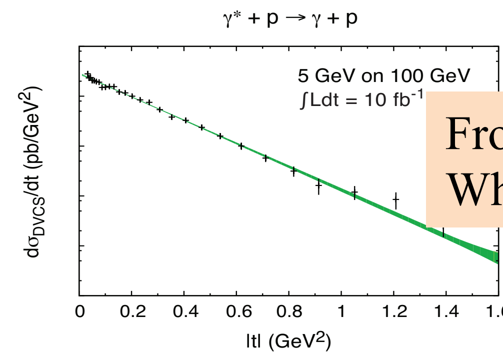
Generalized Parton Distributions

Connected to parton orbital angular momentum

Existing data are either at low Q^2 or have sizable stat. uncertainties

Provide data in wide x&Q^2

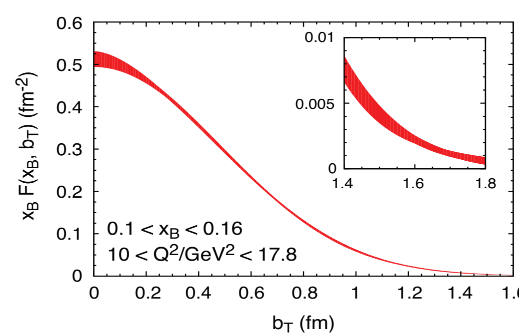
Precise imaging requires higher e-beam energy and luminosity



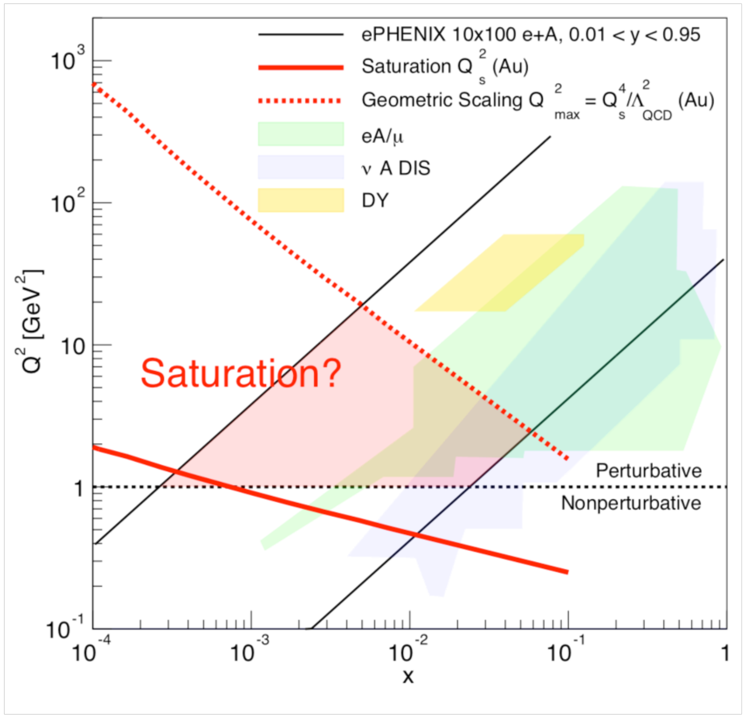
From EIC White paper

ePHENIX with its EMCal and tracking coverage is expected to do similar job (e.g with DVCS)

ePHENIX capabilities for these measurements – similar to generic EIC detector



Gluon Saturation



$$Q_s^2(x) \propto \left(\frac{A}{x}\right)^{1/3}$$

Color Glass Condensate (CGC)

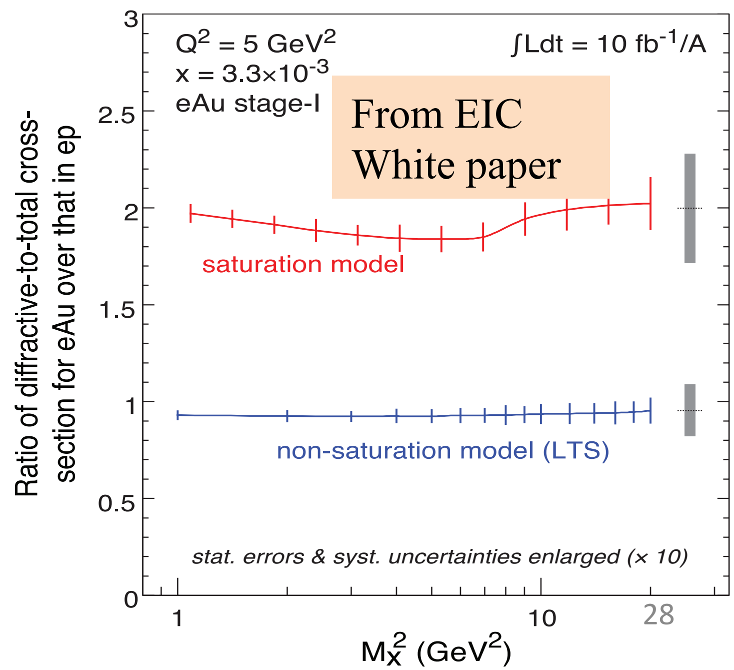
- High gluon density matter
- Direct consequence of gluon self-interaction in QCD

Saturation effects are greatly enhanced in eA collisions:

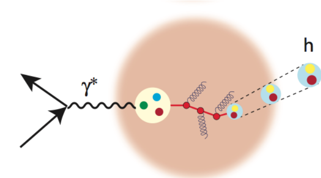
- Collider energy -> low x
- Heavy Ions -> high A

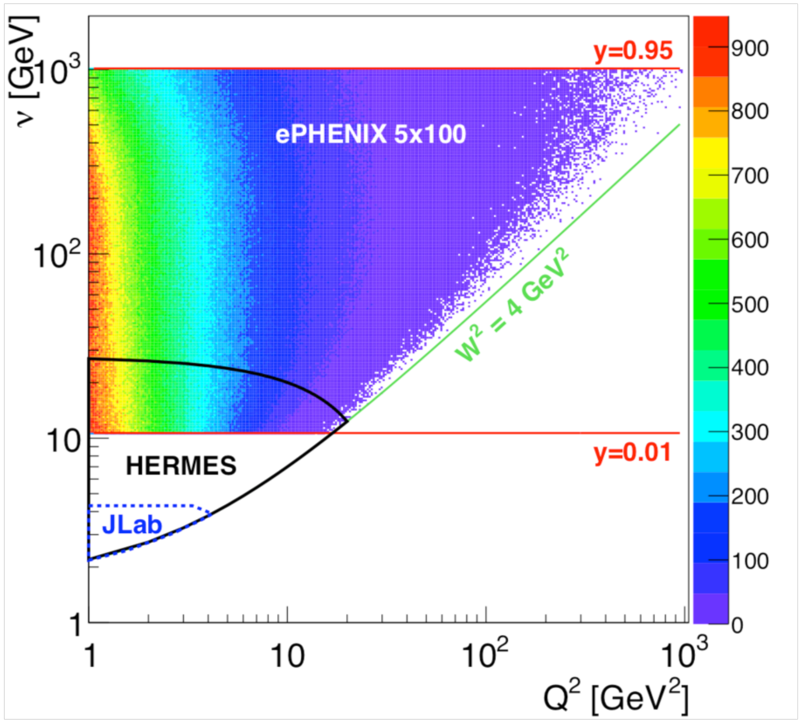
ePHENIX with its HCal and EMCal coverage is expected to do similar job with diffractive measurements

- Diffractive processes are most sensitive to gluon densities ~$(xG)^2$



Propagation and Hadronization





Semi-inclusive eA

Probe color neutralization and hadronization

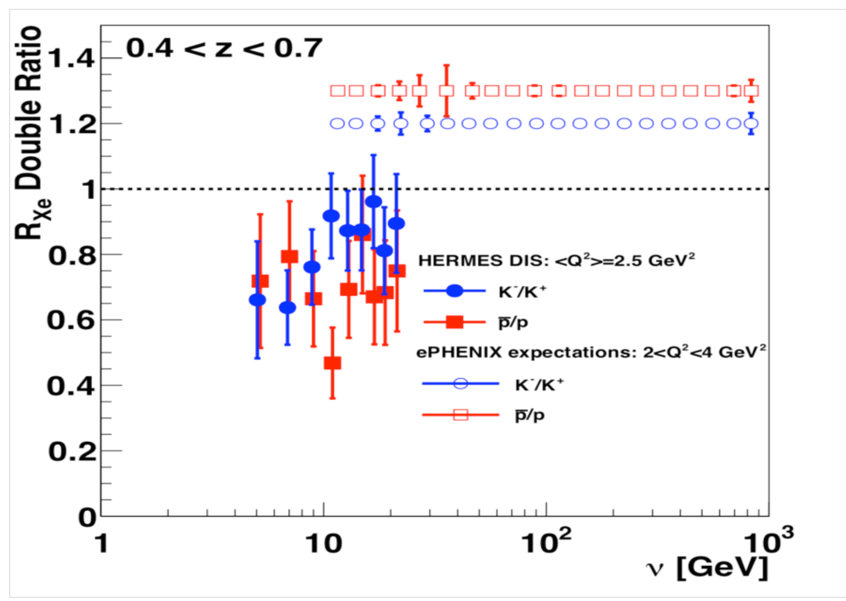
- Different time&distance probed by varying nuclear size and parton energy

Previous experiments are limited by low ν, Q^2

eRHIC:

- Much larger range of ν, Q^2
- Wide range of nuclear size
- Excellent ePHENIX hadron PID up to 60 GeV

ePHENIX with its excellent hadron PID, at eRHIC with its high luminosity and wide kinematic reach, is expected to provide much smaller uncertainties in wider range of ν, Q^2 and nucleus size



Summary

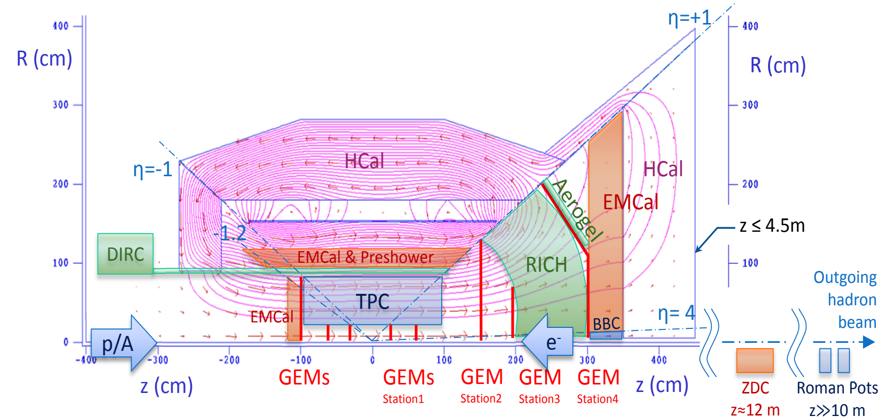
ePHENIX will address a broad range of exciting EIC physics program, that will dramatically advance our understanding of how QCD binds nucleon and forms nuclear matter

Backup

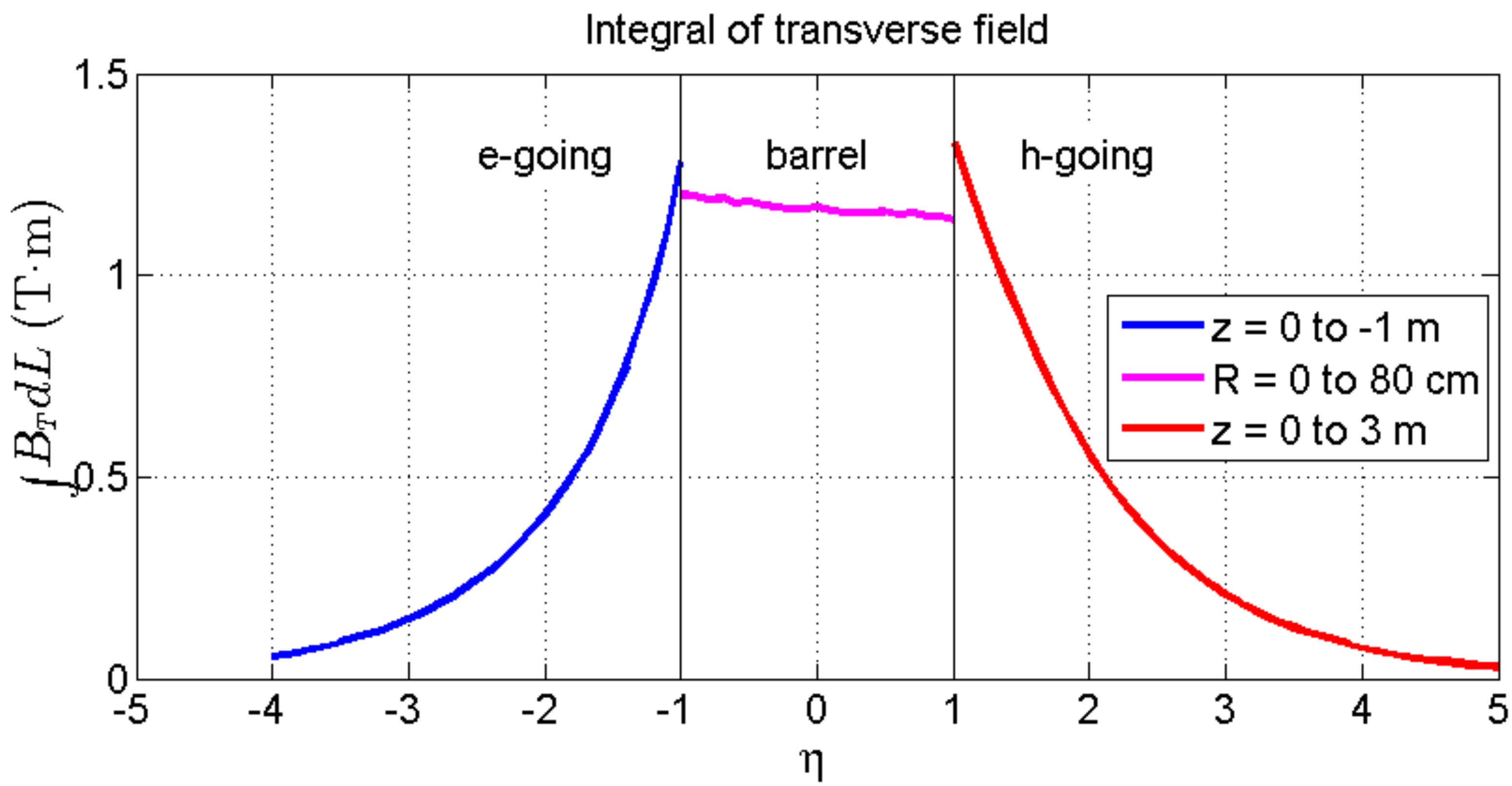
BNL ALD charge for Letter of Intent

- Charge from BNL ALD to PHENIX and STAR to:
  - "Provide specific plans to upgrade/reconfigure the detectors from their present form to first-generation eRHIC detectors"
  - Describe "the physics reach of the upgraded detector"
    - Based on detector capabilities
    - Considering key measurements as described in EIC White Paper (arXiv: 1212.1701)
- ePHENIX LOI Writing Committee formed in May
  - Sasha Bazilevsky (co-chair), Kieran Boyle (co-chair), Abhay Deshpande, Jin Huang, Tom Hemmick, Itaru Nakagawa, Craig Woody, John Haggerty, Dave Morrison, Jamie Nagle
- Submitted to ALD on August 30.

$B_T dL$



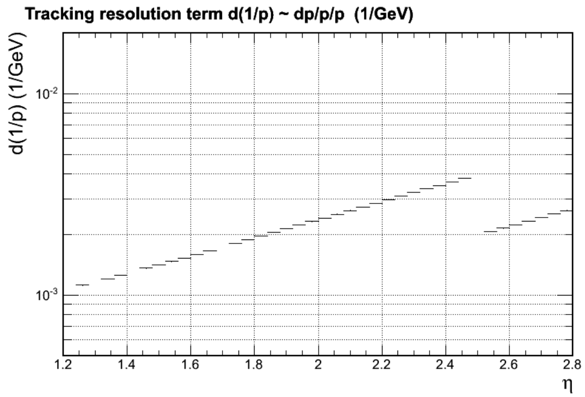
R (cm)
η=+1
η=-1
HCal
HCal
EMCal
Aerogel
-1.2
DIRC
EMCal & Preshower
RICH
z ≤ 4.5m
TPC
EMCal
η= 4
BBC
Outgoing hadron beam
p/A
e-
z (cm)
GEMs
GEMs Station1
GEM Station2
GEM Station3
GEM Station4
z (cm)
ZDC z≈12 m
Roman Pots z≫10 m

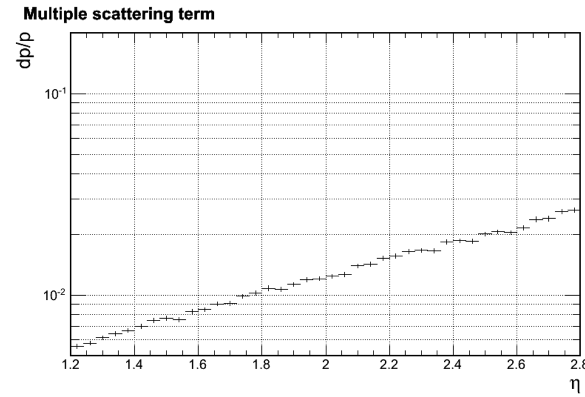


Integral of transverse field
e-going
barrel
h-going
z = 0 to -1 m
R = 0 to 80 cm
z = 0 to 3 m
$\int B_T dL$ (T·m)
η

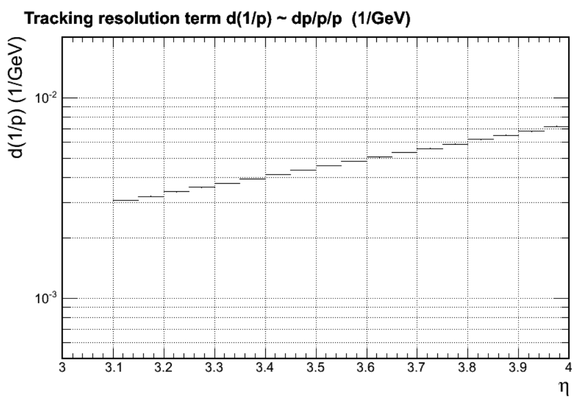
Momentum resolution: GEANT4

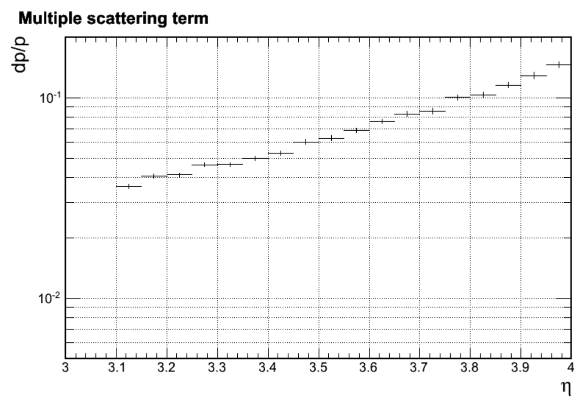
1<η<3





3<η<4





Tracker resolution term,
assuming fixed resolution on sagitta:
1< η <2.5: d($Sagitta_2$) = 120µm for 100 µm tracker resolution
2.5< η <4: d($Sagitta_2$) = 60µm for 50 µm tracker resolution

Multiple scattering term
Without RICH

TPC

LEGS TPC

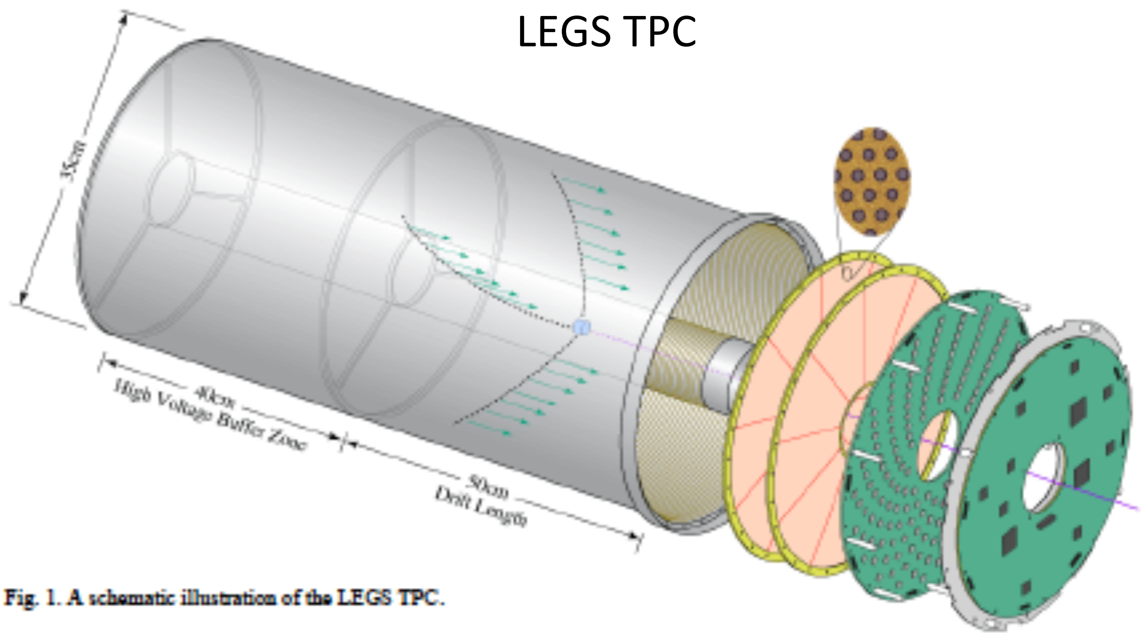


Fig. 1. A schematic illustration of the LEGS TPC.

Chevron-type readout pattern with a pad size 2mm × 5mm

Achieved pos. res. 200 μm

ePHENIX TPC:

R=15-80cm, |z|<95cm

Gas mixture with fast drift time: 80% Ar, 10% CF_4, 10% CO_2

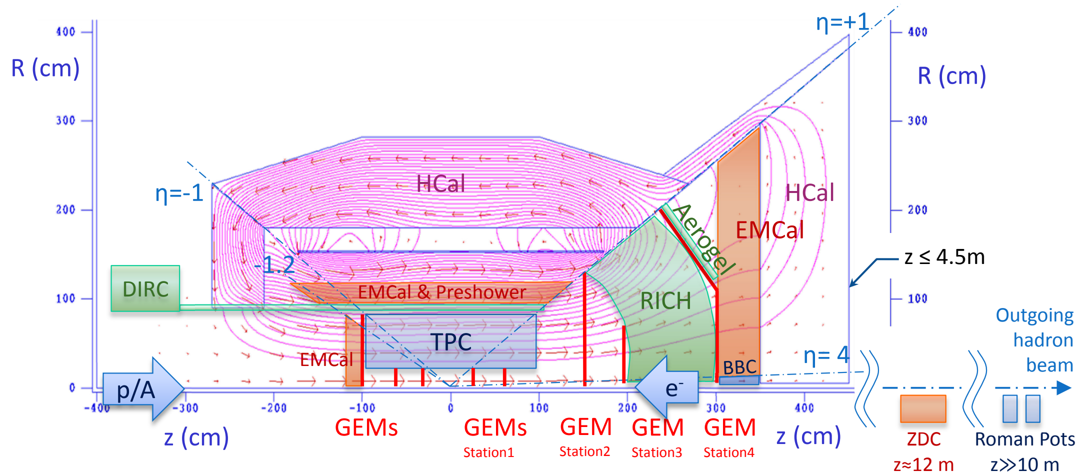
For 650 V/m -> 10cm/μs -> Drift time 10 μs

2×10mm pads –> 180k pads (both ends readout)

Pos. resolution 300 μm (twice longer drift distance tha LEGS)
and 40 readout rows => $\sigma_p/p \sim 0.4\% \times p$

Tracking with GEM

Improved pos. res.
with mini-drift GEM



e-going direction

Station 1-2: z=30, 55cm r=2-15cm

Station 3: z=98 cm

$-3<\eta<-2$: 50μm with 1mm pad

$-2<\eta<-1$: 100μm with 2mm pad

Δr=1cm for St1-2 and Δr=10cm for St3

h-going direction

Station 1: z=17 and 60cm with r=2-15cm

Station 2-4: z=150, 200, 300 cm, $1<\eta<4$

$2.5<\eta<4$: 50μm with 1mm pad

$1<\eta<2.5$: 100μm with 2mm pad

Δr=1-10cm

Collision vertex is necessary in e-going direction:

BBC: η=4-5, z=3m, σ_t=30ps (with MRPC or MCP) -> σ_z=5mm -> const term in σ_p/p~2%

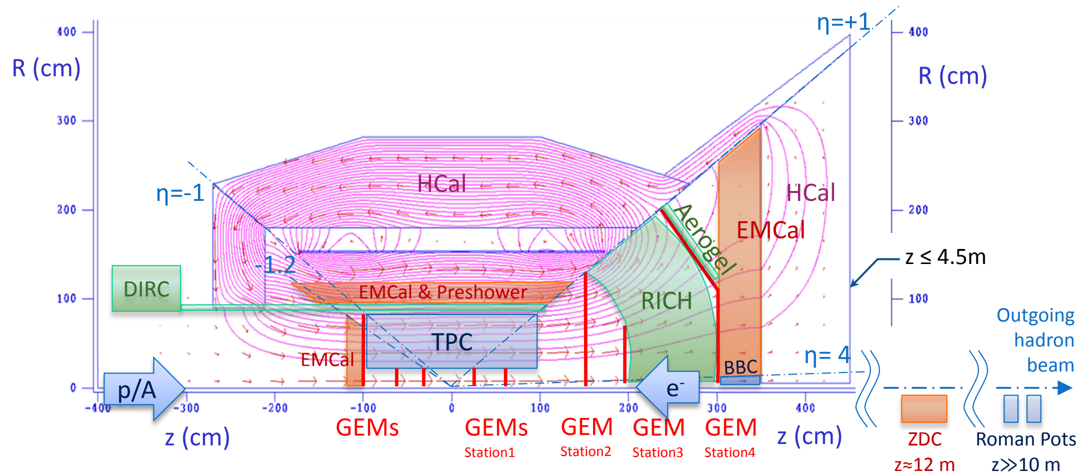
Total channel count: 217k

Large area GEMs are being developed in CERN for CMS (needed for our St 2-4)

Calorimetry

EMCal coverage -4<η<4
HCal coverage -1<η<5

Readout: SiPM



e-going direction

Crystall EMCal:

- 2cm×2cm
- 5k towers
- $\sigma_E/E \sim 1.5\%/\sqrt{E}$
- $\sigma_x \sim 3mm/\sqrt{E}$

Barrel (sPHENIX)

Tungsten-fiber EMCal:

- 2cm×2cm
- 25k towers
- $\sigma_E/E \sim 12\%/\sqrt{E}$

Steel-Sc HCal:

- 10cm×10cm
- 3k towers
- $\sigma_E/E \sim 100\%/\sqrt{E}$

h-going direction

Pb-fiber EMCal:

- 3cm×3cm
- 26k towers
- $\sigma_E/E \sim 12\%/\sqrt{E}$

Steel-Sc HCal:

- 10cm×10cm
- 3k towers
- $\sigma_E/E \sim 100\%/\sqrt{E}$

Hadron PID

DIRC

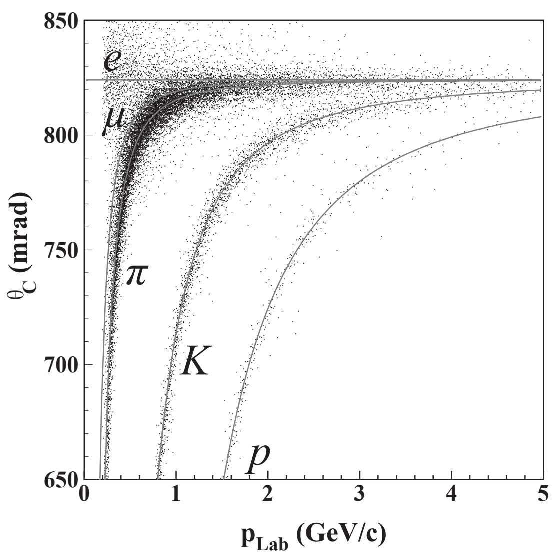
$-1<\eta<1$
Mirror focusing
Threshold for π/K/p:
0.2/0.7/1.5 GeV

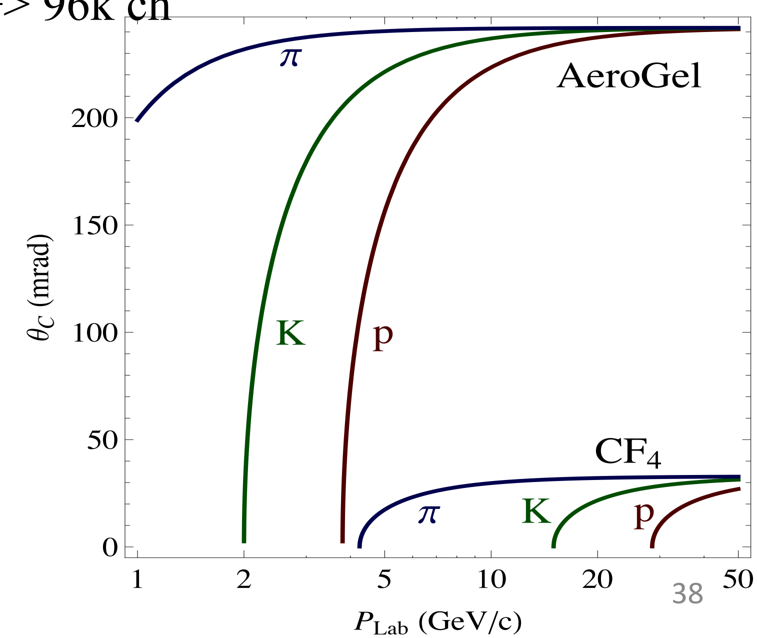
Gas RICH (CF4)

$1<\eta<4$
Mirror focusing
Threshold for π/K/p:
4/15/29 GeV
6 azimuthal segments
Photodetection: GEM with CsI
Area $6\times0.3m^2$ –> 96k ch
In gas volume!

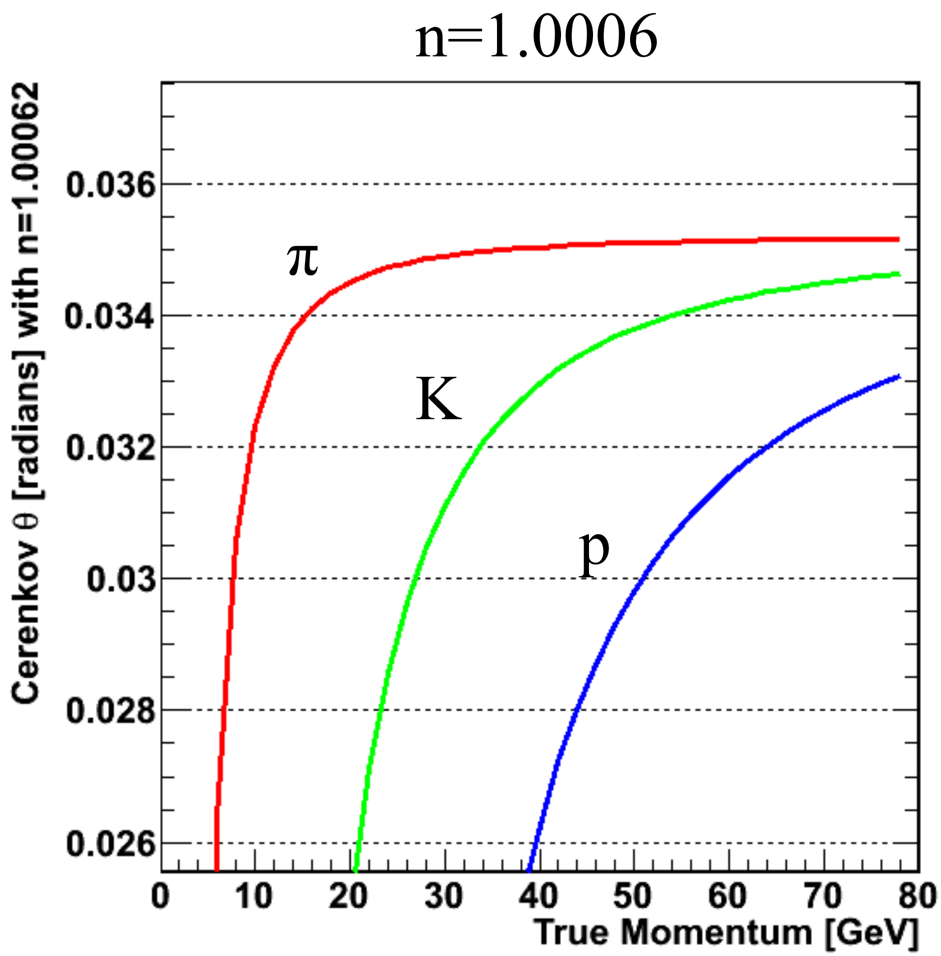
Aerogel

$1<\eta<2$
Proximity focused
Threshold for π/K/p:
0.6/2/4 GeV





Cerenkov Angle in CF4



Hadron PID: gas RICH

Goals and assumptions/restrictions

1m gas volume along the track => F=1m => R=2m

Z>1.5m (optimal sagitta plane)

Z<3.0m (EMCal)

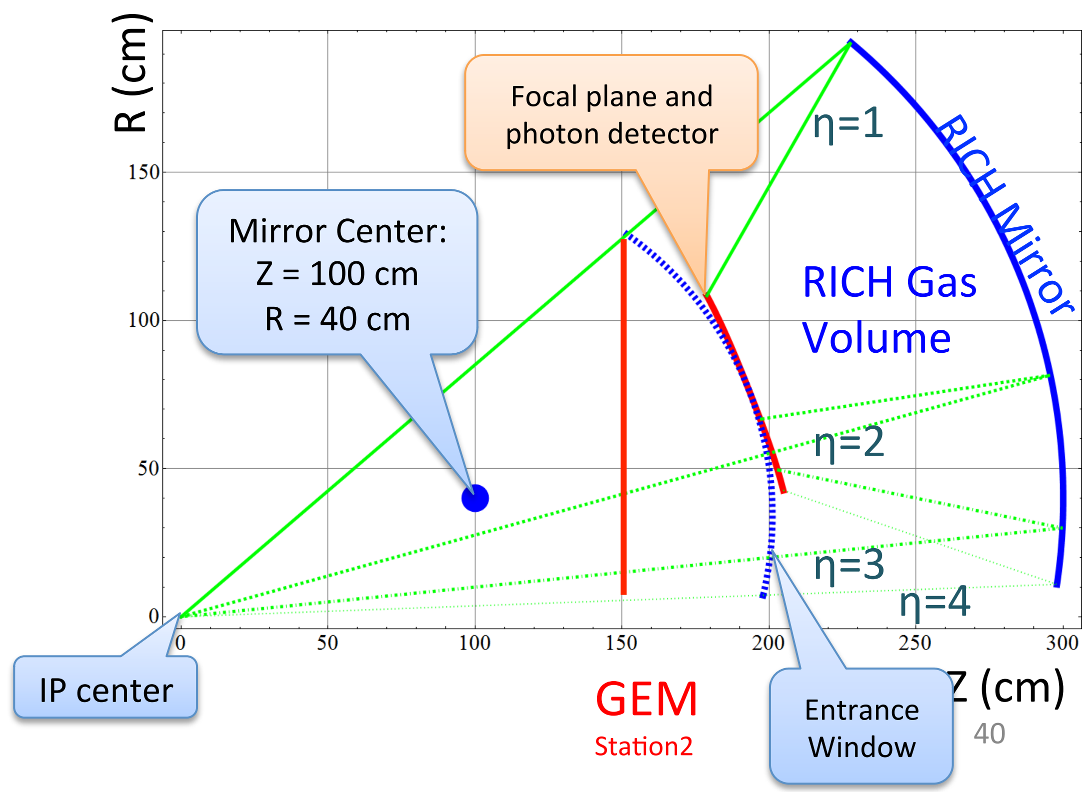
Photon detector inside tracking volume –> GEM as thin –> flat

Low number of edges between mirrors

Small area for photon readout

Moving mirror center to beam line:

- Focal plane not flat
- Steeper impact angle on the photon detector
- Photon detector closer to beam line
- RICH volume moves to z<1.5m



Hadron PID: gas RICH

CF4 (n=1.00062)

Ring resolution

Ring radius resolution: $2.5\%/\sqrt{N_\gamma}$

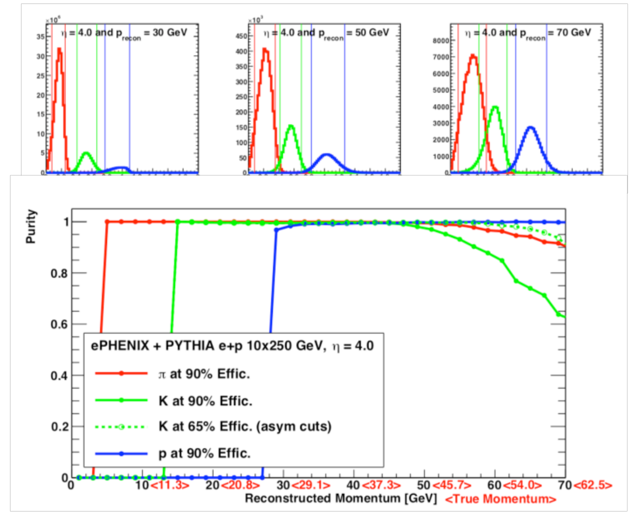
- From current EIC R&D studies
- LHCb and COMPASS claimed 1% per photon

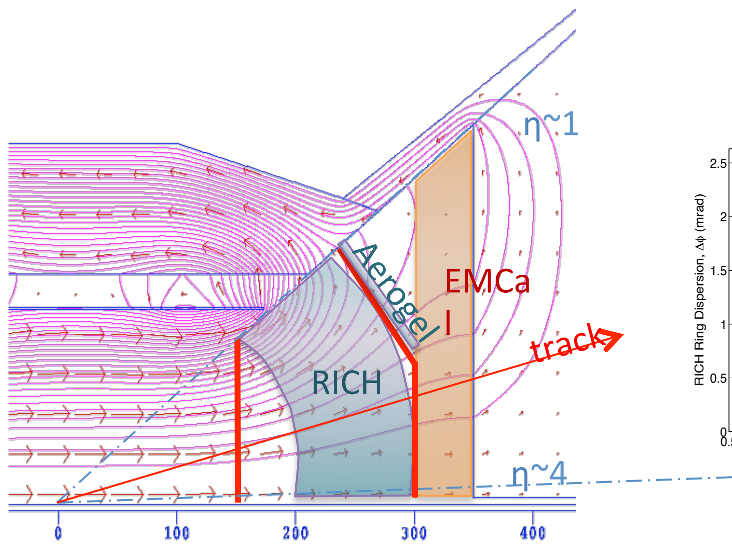
Residual magnetic field (~0.5 T) bends tracks radiating photons => ring smearing

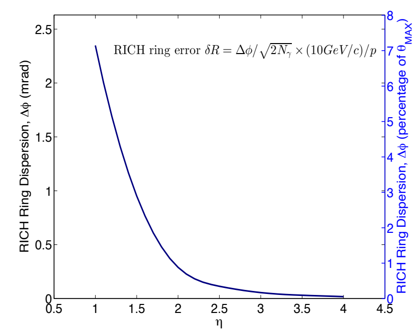
- Since field is near parallel to tracks the effect is minimal

Off-center vertex tracks have shifted focal plane => ring smearing

- For $\eta=1$ and z=40cm => ring dispersion $5\%/\sqrt{N_\gamma}\times(10\ \mathrm{GeV/c})\ /\ p$
- For larger η effect is smaller





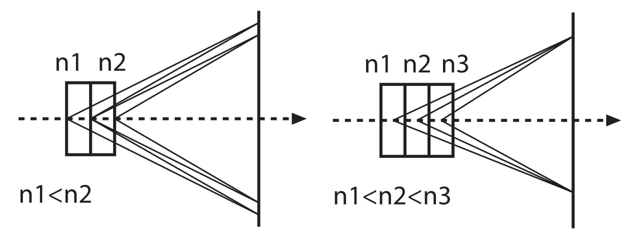


Ring resolution limits PID at higher p

Hadron PID: Aerogel

Allows to identify K for 3<p<10 GeV

Focusing



Challenges:

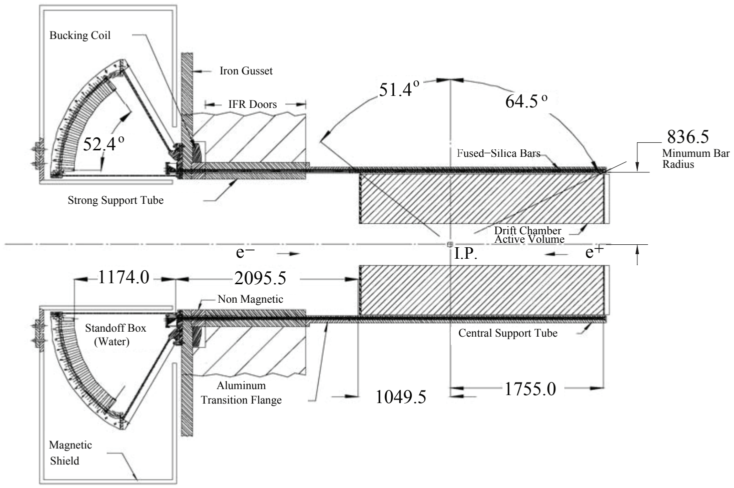
- Fringe field
- Low light output
- Visible wavelength range
- Limited space for light focusing

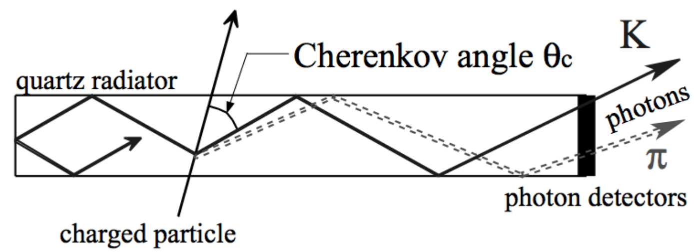
Photon detection:

Microchannel Plate Detector

- Multi-alkali photocathode
- Also ToF with σ=20-30ps
- Being developed by LAPPD Collaboration

Hadron PID: DIRC





BaBar DIRC

Quartz radiator bars, Cerenkov light internally reflected

No focusing => Large water filled expansion volume

PMT for readout

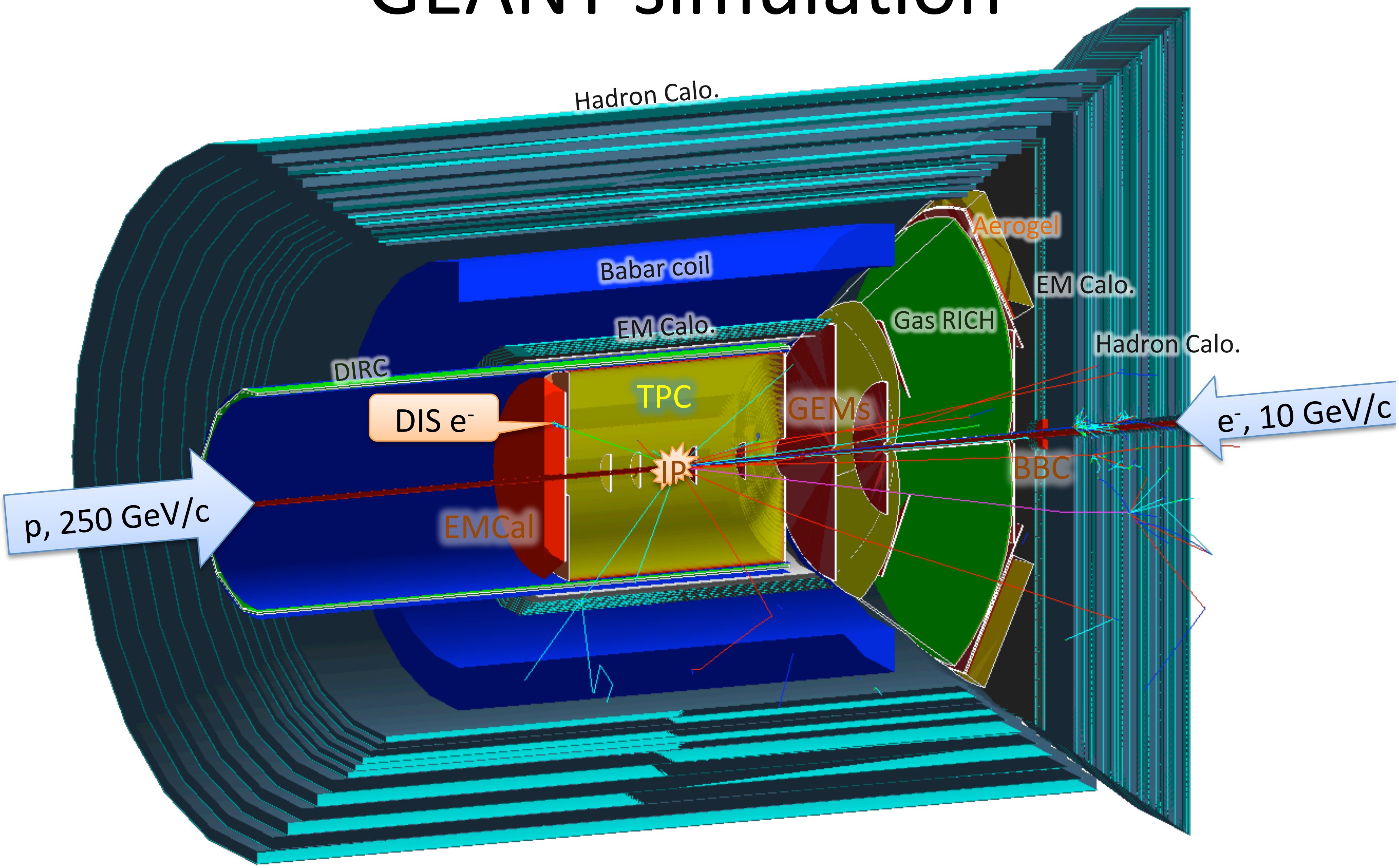
ePHENIX DIRC

Mirror Focusing to avoid large expansion region

Pixelated multi-anode PMT for readout

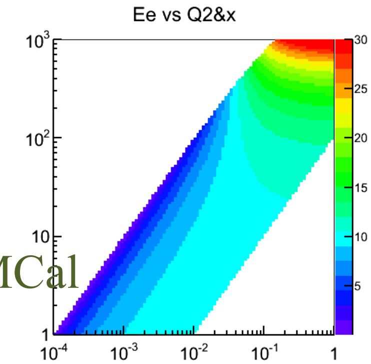
Ring resolution limits PID at higher p

GEANT simulation

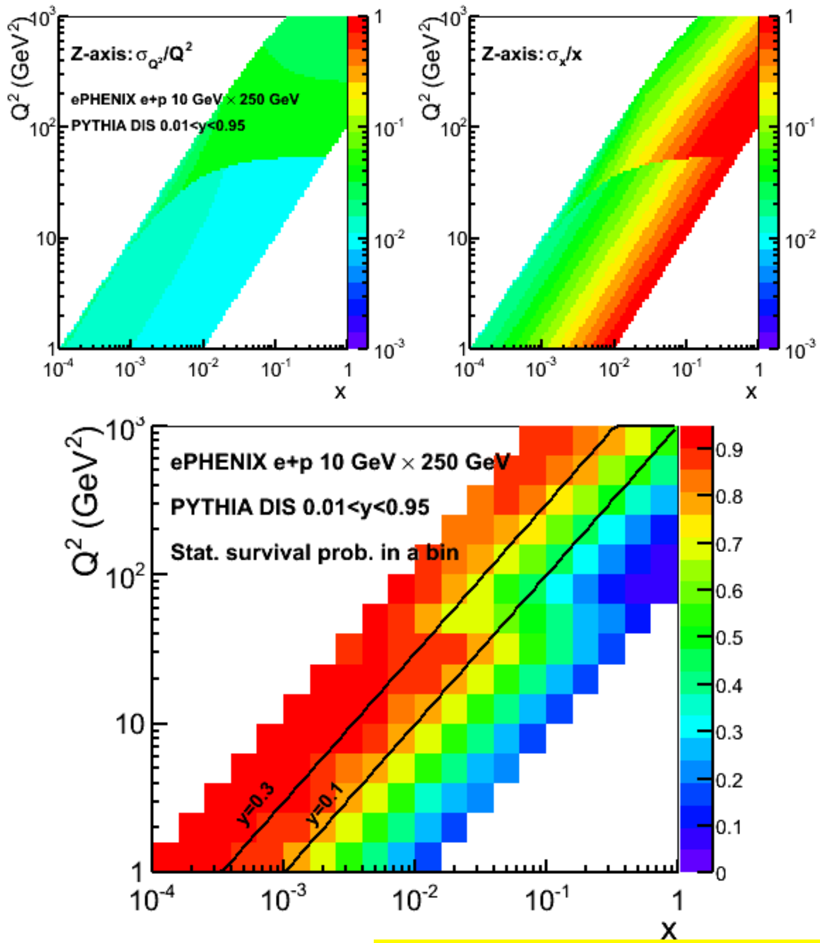


Simulation and analysis software common with sPHENIX and PHJENIX

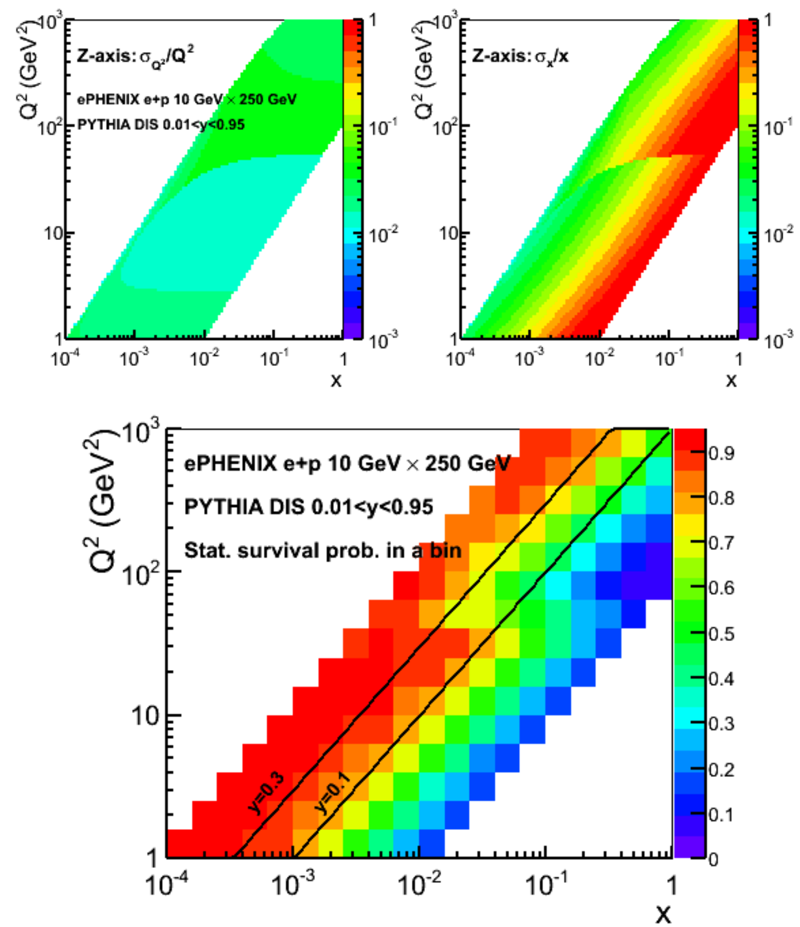
DIS kinematics: angle from EMCal



With perfect angle measurements

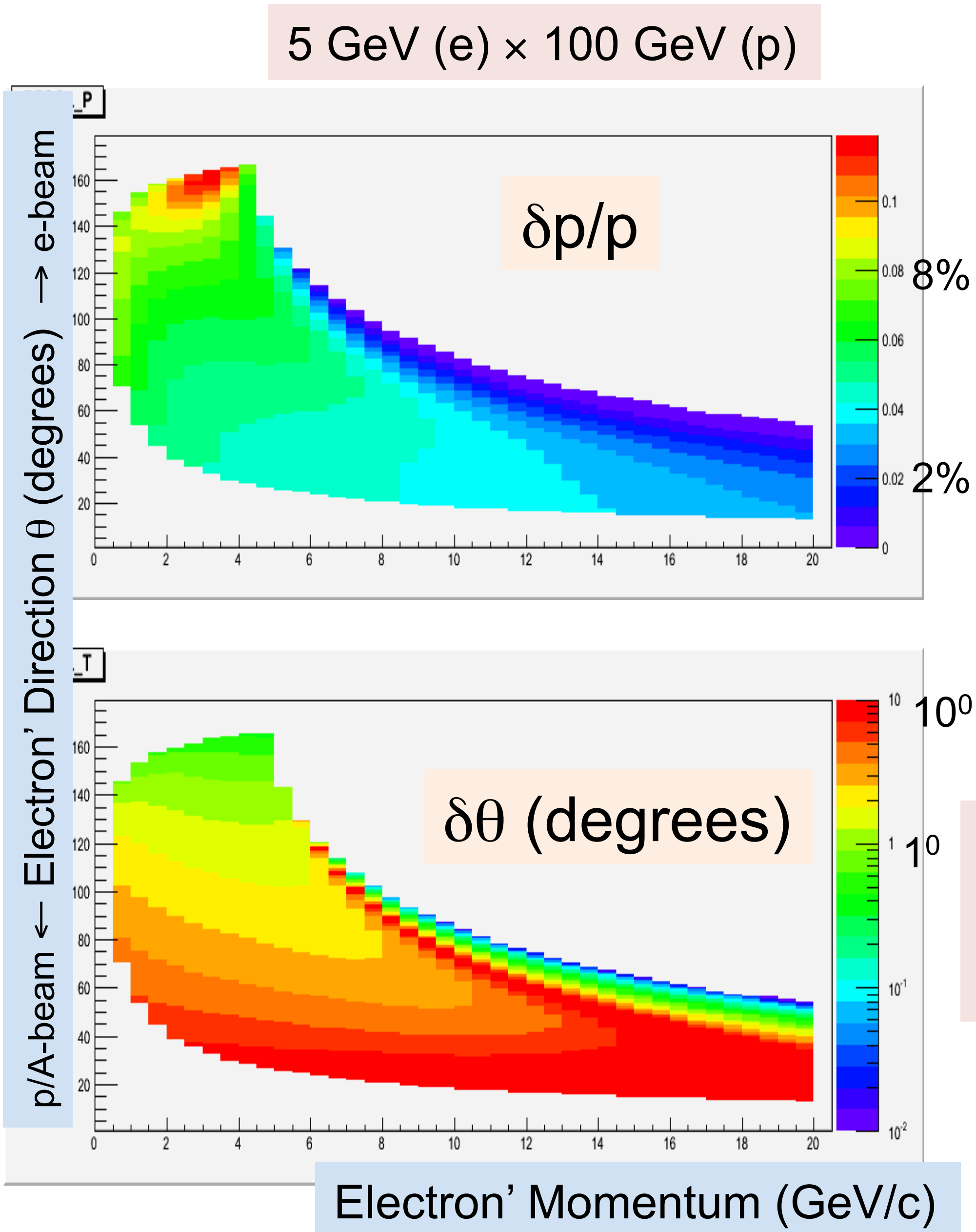


With angle smearing due to EMCal pos. resolution



Only minor effect from angle measurements with EMCal

Tom H: Momentum and angle resolution



Inclusive measurements:

$$\sigma_{red} = F_2(x,Q^2) - \frac{y^2}{Y_+} F_L(x,Q^2)$$

$$(x,Q^2) \rightarrow (p,\theta)_{e'}$$

Resolution → Systematics → Unfolding

Assume: σ_{syst}~1/5 of systematics

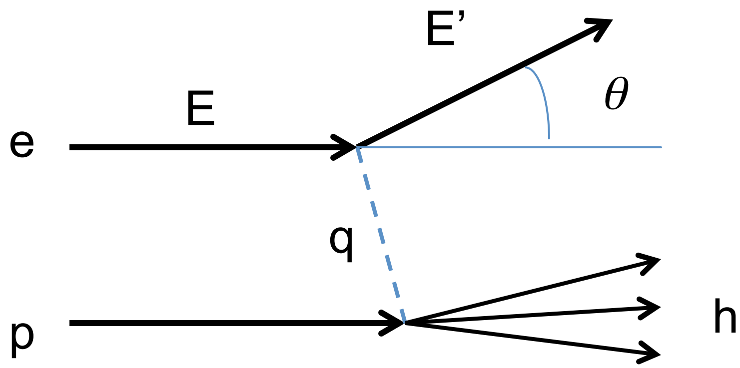
0.1×0.1 binning in $\log_{10}(x) \times \log_{10}(Q^2)$

Require: 1% uncertainty in each bin

"Reasonable" resolutions may be enough:

δp/p ~ 2-8%

δθ ~ 1 degree



Electron vs Jacquet-Blondel

Electron

$$Q^2 = 4EE'\sin^2\left(\frac{\theta}{2}\right)$$

$$y = 1 - \frac{E'}{E}\cos^2\left(\frac{\theta}{2}\right)$$

$$x = \frac{Q^2}{sy}$$

$y \to 0$: $\sigma_y/y \sim 1/y$

JB

$$Q^2_{JB} = \frac{p^2_{T,h}}{1 - y_{JB}} \qquad p^2_{T,h} = \left(\sum_h p_{x,h}\right)^2 + \left(\sum_h p_{y,h}\right)^2$$

$$y_{JB} = \frac{(E - p_z)_h}{2E_e} \qquad (E - p_z)_h = \sum_h (E_h - p_{z,h})$$

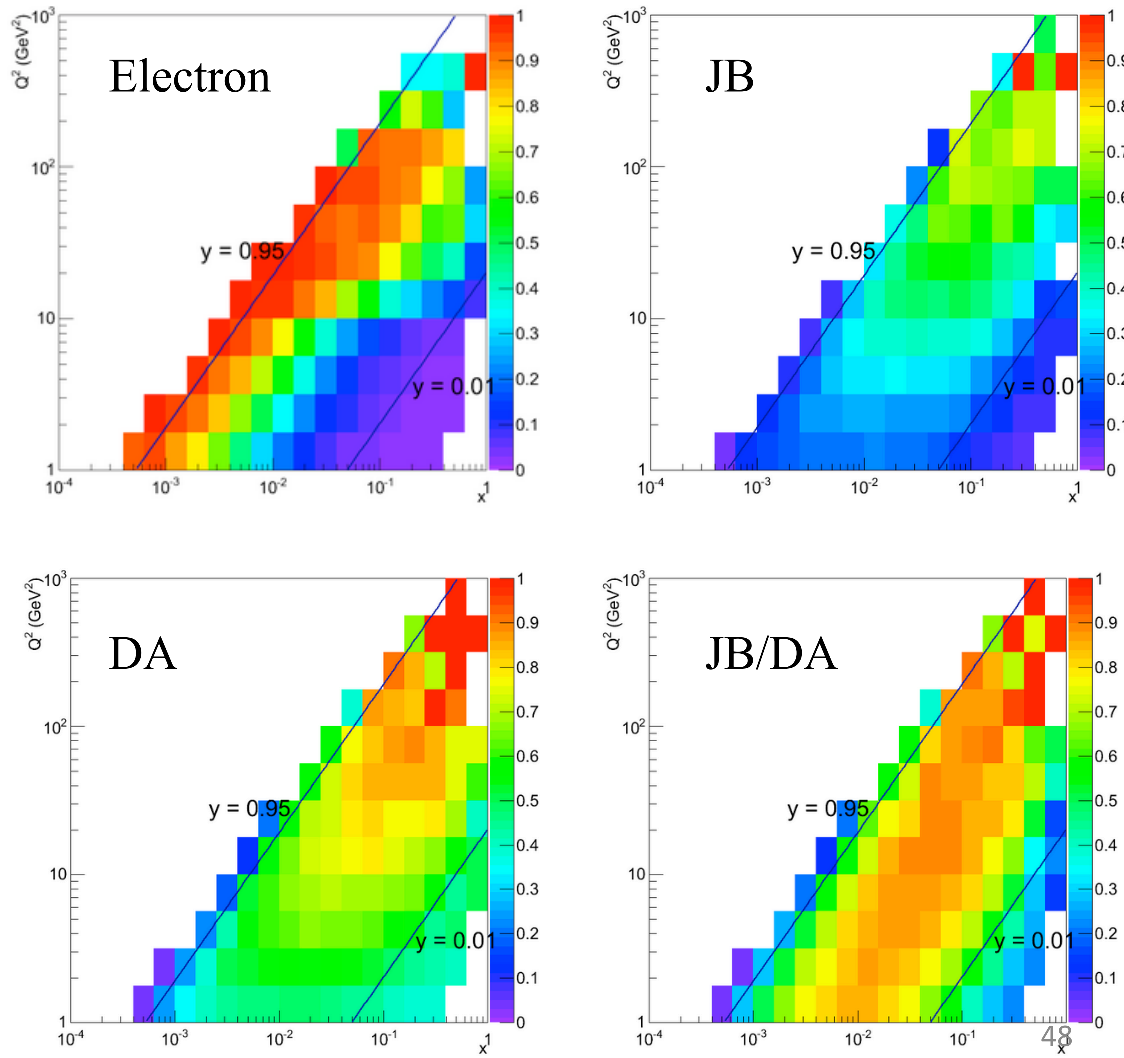
$$x_{JB} = \frac{Q^2_{JB}}{sy_{JB}}$$

$y \to 0$: $\sigma_y/y \sim$ const

JB

EIC group studies:
https://wiki.bnl.gov/eic/index.php/Q2-x_bin_migration

JB and DA methods give better resolution at lower y and higher Q^2



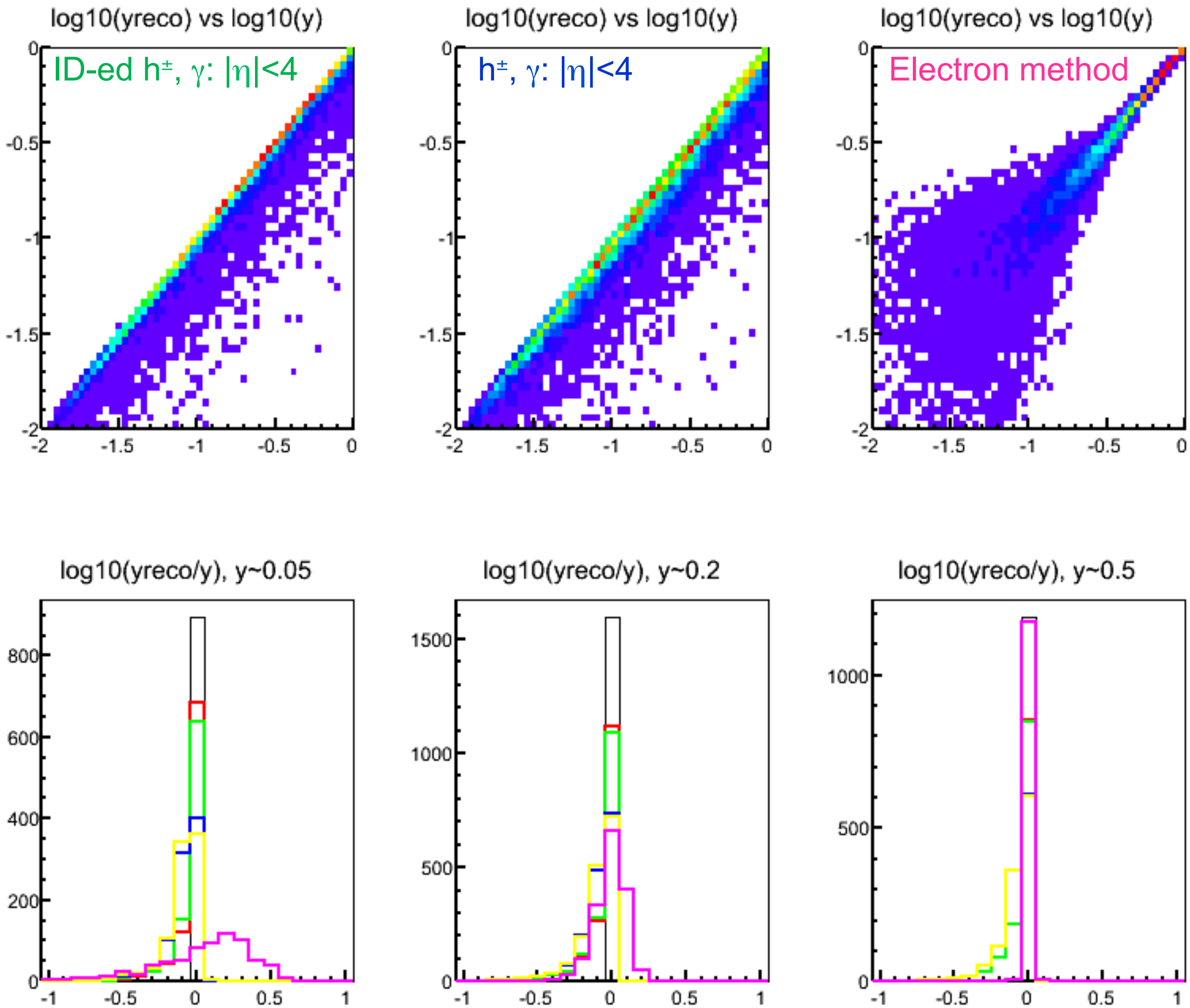
Our studies:

- Enough to measure hadrons in |η|<4
- Hadron PID is important

  Particularly for lower Q^2
- For y<0.2 – enough to measure in -1<η<4

  The acceptance we'll equip with hadron ID

JB: 5x100 Q2>10

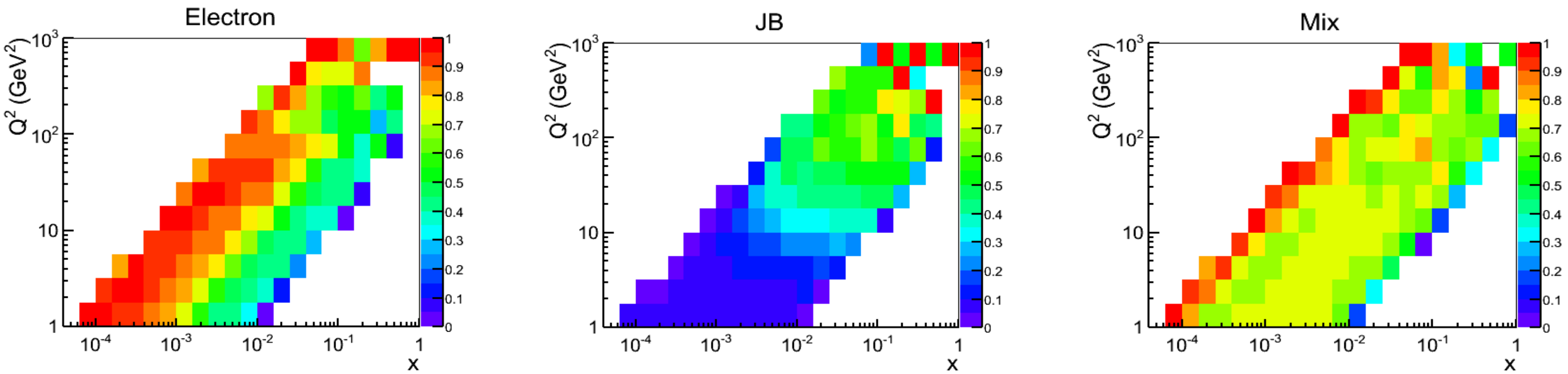


- Enough to measure hadrons in |η|<4
- Hadron PID is important
  - Particularly for lower Q^2
- For y<0.2 – enough to measure in -1<η<4
  - The acceptance we'll equip with hadron ID

All
ID-ed h±, γ
ID-ed h±, γ: |η|<4
h±, γ: |η|<4
h±, γ: |η|<4, p-smeared
Electron method

Green ~ Red
Blue ~ Yellow

Electron vs JB vs Mix

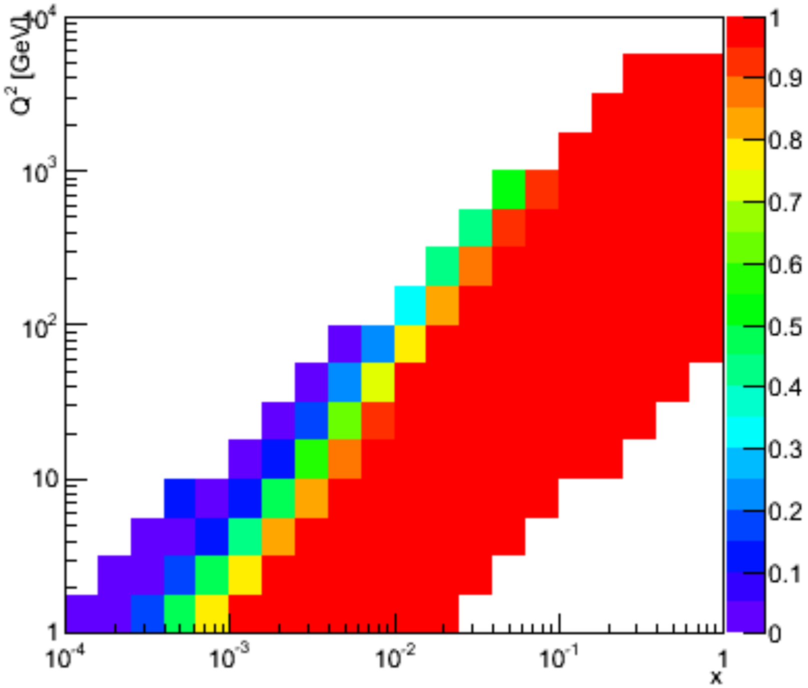


For 15 GeV × 250 GeV beam energy configuration, event purity in (x,Q^2) bins, defined by the likelihood of an event to remain in its true (x,Q^2) bin after resolutions smearing; left – for electron method, middle – for Jacquet-Blondel method, and right – for "Mixed" method, when Q^2 is defined from electron method, y is defined from Jacquet-Blondel method, and $x=Q^2/(sy)$.

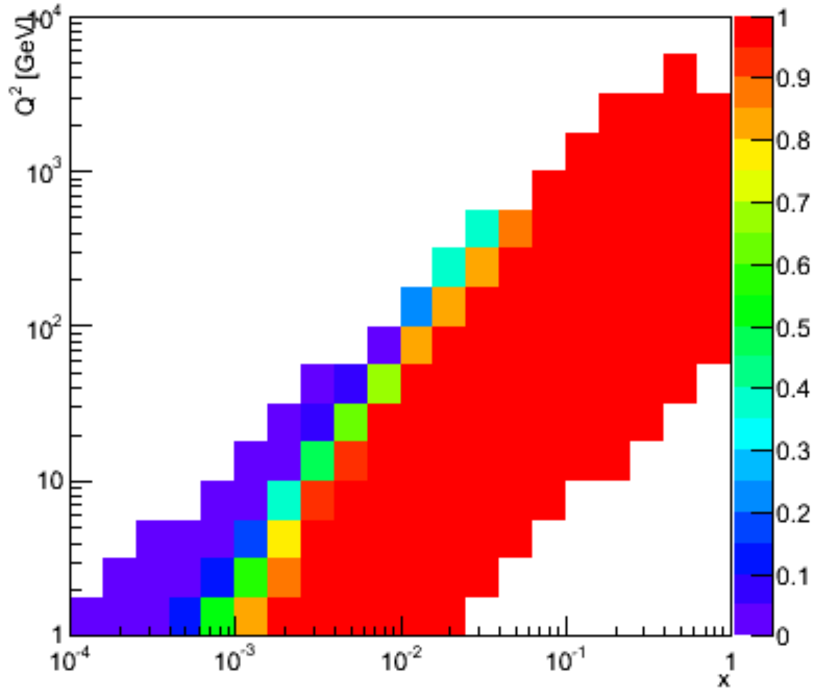
(x,Q2) loss due to no ePID in e-going direction

e+p 10 GeV × 250 GeV
PYTHIA DIS 0.01<y<0.95 W^2>10 GeV^2

0.30<z<0.35



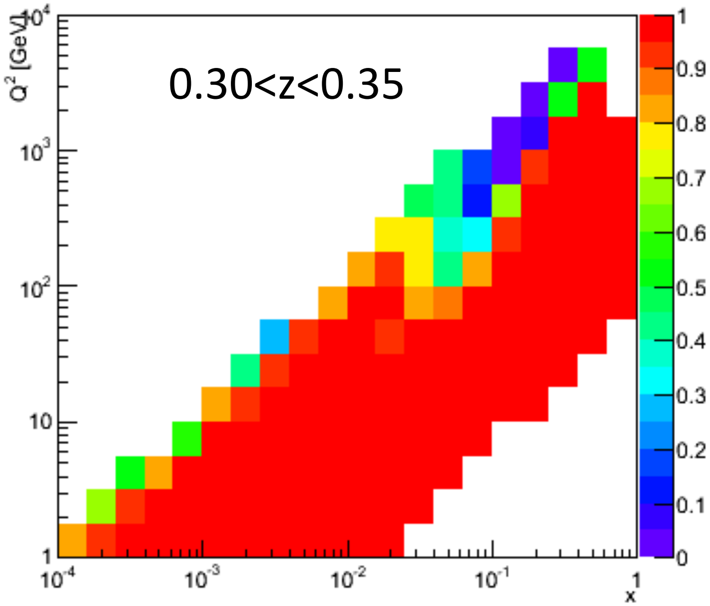
0.70<z<0.75

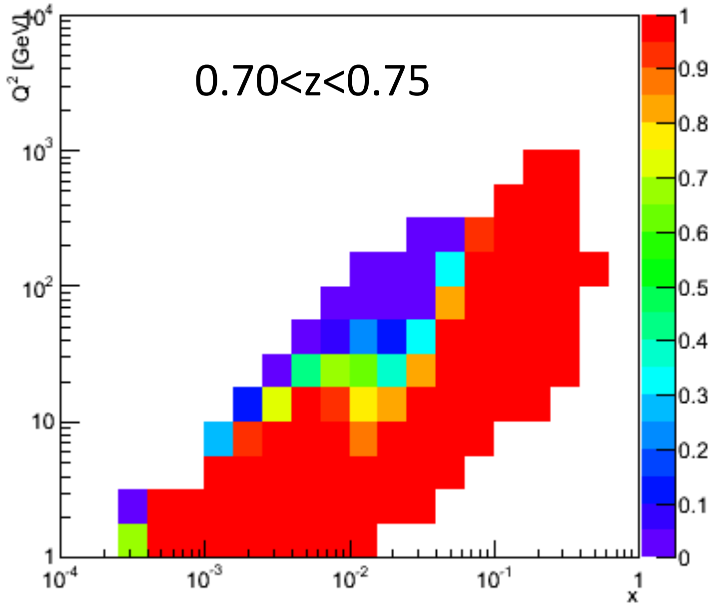


If better DIRC?

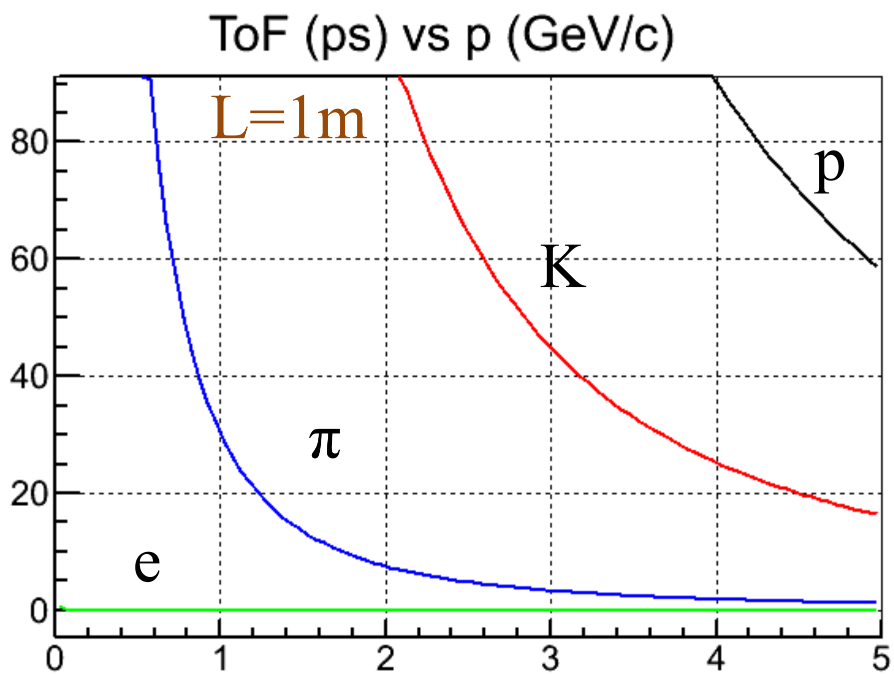
e+p 10 GeV × 250 GeV
PYTHIA DIS 0.01<y<0.95 W^2>10 GeV^2

"Normal" DIRC: pi/K separation up to 3.5 GeV/c
Improved DIRC: pi/K separation up to 6 GeV/c





ToF for PID?



With 10 ps resolution including t_0:

e/π separation at <1 GeV/c

K/π separation at <4 GeV/c

Need t_0 (σ<10ps) and vertex (σ~1mm)

Cost and schedule

Table 4.1: Estimated equipment costs for the ePHENIX detector (in $M).

		Cost	Overhead	Contingency	Total
Calorimeters	Endcap Crystal	3.40	0.47	1.93	5.80
	Forward EMCAL	1.41	0.27	0.84	2.53
	Forward HCAL	3.90	0.68	2.29	6.87
Tracking	TPC	0.75	0.19	0.47	1.41
	GEM Trackers	0.71	0.18	0.44	1.33
Beamline instrumentation	Roman pots	0.23	0.04	0.14	0.41
	Beam-Beam counter	0.20	0.05	0.13	0.38
Particle ID	DIRC	12.50	1.75	7.13	21.38
	RICH	2.00	0.50	1.25	3.75
	Aerogel	1.55	0.22	0.88	2.65
Electronics/sensors	Endcap Crystal	0.89	0.22	0.56	1.67
	Forward EMCAL	3.09	0.43	1.76	5.28
	Forward HCAL	0.38	0.05	0.22	0.65
	TPC	2.80	0.81	1.81	5.42
	GEM Trackers	0.71	0.18	0.44	1.33
	DIRC	0.77	0.19	0.48	1.44
	RICH	0.69	0.17	0.43	1.29
	Aerogel	1.55	0.39	0.97	2.91
	Roman Pots	0.11	0.03	0.07	0.21
	Beam-Beam	0.10	0.02	0.06	0.19
	Data Collection	0.60	0.15	0.38	1.13
	Trigger	0.60	0.15	0.38	1.13
Integration/Mechanical		3.00	0.93	1.96	5.90
Total		41.94	8.08	25.01	75.02

Table 4.2: Total estimated labor for ePHENIX detector construction.

	FY21	FY22	FY23	FY24	Total
Physicist FTE	10	9	10	13	42
Physicist cost	3.02	2.78	3.45	4.60	13.85
Engineer FTE	10	10	7	5	31
Engineer cost	2.59	2.66	2.02	1.49	8.76
Technician FTE	1	1	11	19	31
Technician cost	0.21	0.21	2.29	4.16	6.87
Total FTE	20	19	28	37	104
Total cost	5.81	5.65	7.77	10.25	29.49

Table 4.3: Schedule of Critical Decisions and reviews necessary for construction FY2021–FY2024.

CD0	4Q2016
CD1 review	4Q2017
TDR preparation	4Q2017 - 3Q2019
CD2/3 review	4Q2019
FY2021 budget briefing	1Q2020
Construction start	4Q2020 (FY2021)
CD4	3Q2024 (FY2024)
Commissioning run	1Q2025

Run Schedule for RHIC

Years	Beam Species and Energies	Science Goals	New Systems Commissioned
2013	• 510 GeV pol p+p	• Sea quark and gluon polarization	• upgraded pol'd source • STAR HFT test
2014	• 200 GeV Au+Au • 15 GeV Au+Au	• Heavy flavor flow, energy loss, thermalization, etc. • Quarkonium studies • QCD critical point search	• Electron lenses • 56 MHz SRF • full STAR HFT • STAR MTD
2015-2016	• p+p at 200 GeV • p+Au, d+Au, ^{3}He+Au at 200 GeV • High statistics Au+Au	• Extract η/s(T) + constrain initial quantum fluctuations • More heavy flavor studies • Sphaleron tests	• PHENIX MPC-EX • Coherent electron cooling test
2017	• No Run		• Electron cooling upgrade
2018-2019	• 5-20 GeV Au+Au (BES-2)	Search for QCD critical point and deconfinement onset	• STAR ITPC upgrade
2020	• No Run		• sPHENIX installation
2021-2022	• Long 200 GeV Au+Au w/ upgraded detectors • p+p/d+Au at 200 GeV	• Jet, di-jet, γ-jet probes of parton transport and energy loss mechanism • Color screening for different QQ states	• sPHENIX
2023-24	• No Runs		Transition to eRHIC